Shelterbelts and Windbreaks

J.M.CABORN

50/-

SHELTERBELTS AND WINDBREAKS

J. M. CABORN

In a windy climate such as Britain's providing shelter is important, whether it is a case of transforming cold, windswept country into productive farmland or affording a quiet corner in parks and gardens. Shelterbelts and windbreaks perform many beneficial roles improving environmental conditions for plants and animals; increasing the output from arable farms and upland grazings; countering salt sea winds; checking fenland and light soils from blowing; reducing the burden of heat losses from houses and glasshouses; and, in some cases, combining shelter with timber growing. This book discusses the need for shelter and shows how to create, and make the best use of, wind protection, not only on lowland or hill farms and country estates but also in gardens, parks and recreation grounds, orchards and market gardens, in seaside situations and towns and along roadways. Practical advice is given on the design, establishment and maintenance of windbreaks of all sizes and also on the restoration of old shelterbelts.

Shelterbelts and Windbreaks has been written for landowners, farmers, estate agents, foresters, landscape architects, park superintendents, gardeners (whether amateur or commercial) and students—in fact, for all interested in tempering the wind and ameliorating the local climate.

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Preface

Planting for shelter is not new: it was ordained by the Scottish Parliament in 1457, achieved—perhaps accidentally—by the 18th-century landscape designers and deliberately planned by the agricultural improvers. It is older than the terms, *shelterbelt* and *windbreak*, coined in America a hundred years ago and since added to our vocabulary.

Shelterbelts and windbreaks perform many roles: controlling the ravages of wind; improving environmental conditions for plants, animals and people; increasing the output from arable farms and upland grazings; countering salt sea winds; checking fenland and light soils from blowing; reducing the burden of heat losses from houses and glasshouses; and in some cases yielding timber as well as shelter.

Windiness affects a wide range of activities and recently there has developed a renewed interest in the value of shelter and the means by which it can be achieved; hence, the demand for a practical guide and handbook catering for all who are interested in or concerned with providing shelter. This book has been written for landowners, farmers, estate agents, foresters, landscape architects, park superintendents, gardeners (whether amateur or commercial) and students. Advice is given on the design, establishment and maintenance of windbreaks for various purposes, ranging from purely functional shelterbelts to smaller windbreaks combining utility with ornament. Suggestions are also made for the restoration of old and near-derelict shelterbelts, which will otherwise be lost eventually from the landscape.

In these suggestions, the familiar tree and shrub species are easily recognized; the ornamentals and cultivars may be less well known. Botanical nomenclature is beset with frequent name changes and with few exceptions I have adhered to names used in the Royal Horticultural Society Dictionary.

J. M. CABORN

Edinburgh
1st March 1965

Contents

1 WIND AND CLIMATE *page* 17
2 THE VALUE OF SHELTER FOR HOUSE AND GARDEN 38
3 SHELTER FOR PARKS, ROADS AND RURAL ESTATES 56
4 SHELTER AND FARM CROPS 71
5 SHELTER AND LIVESTOCK 85
6 THE SHELTERING TREES 101
7 DESIGNING SMALL WINDBREAKS 137
8 WINDBREAKS FOR SPECIAL PURPOSES 166
9 PLANTING FOR SHELTER ON THE FARM 199
10 MAINTENANCE AND RESTORATION OF OLD SHELTERBELTS 242
11 SHELTERBELTS AND TIMBER 255
12 FARMING WITH FORESTRY 263
APPENDIX: Key to the Selection of Tree Species 276
Table of Plant Requirements per Acre 281
BIBLIOGRAPHY 282
INDEX 283

Illustrations

LINE

1 A 30-ft high shelterbelt affects wind speed for 100 yards in front of the trees and 300 yards down-wind. *page* 27

2 Plan of wind conditions in the vicinity of a moderately dense shelterbelt. Wind speed expressed as a percentage of the free, unobstructed wind. 28

3 Parallel belts have no apparent cumulative effect on wind abatement (after Nägeli). 29

4 Effect of (a) moderately penetrable, and (b) dense windbreaks on the flow of wind. Figures circled denote approximate wind speeds in the various sections. Figures below the line refer to horizontal distances where windbreaks are 30 ft tall (after Kuhlewind *et al.*). 32

5 Patterns of wind abatement in the vicinity of shelterbelts of different density (after Nägeli and Caborn). 33

6 The ability of shelterbelts to check the wind and afford shelter exhibits wide variation (after Nägeli). 35

7 Guide to the shading effect of windbreaks running (a) from East to West, (b) from North-West to South-East, and (c) from North to South. Shadow lengths expressed in multiples of windbreak height, *H*. 43

8 Dense windbreaks (a) create frost pockets. Penetrable windbreaks (b) allow cold air to drain away and are important at the foot of sloping gardens and orchards. *page* 47

9 Dense belts can be used to divert cold air from orchards. Open belts are necessary on lower slopes to allow maximum drainage. 48

10 Wind accelerates under open avenue belts, reducing their value for shelter (after Nägeli). 58

11 Snow drift patterns observed beside a Canadian shelterbelt, showing the influence of the up-wind terrain on drift formation. 63

12 An early nineteenth-century system of shelterbelts, Midlothian. 66

13 Average effect of a large sample of windbreaks on crop yields, U.S.A. (after Bates). 76

14 Belts forming a series of 'baffle-plates' along a windswept valley. 98

15 Shelter plantations for livestock. (a), (b) and (c) are nineteenth-century Scottish examples of stells combining plantations; (d) and (f) are examples of the various shapes adopted for hill planting; (e) Cadman's 'Manx-leg' plantation, affording protection against all quarters. 100

16 Obvious wind funnels, as at (a) should be sealed off. Checking cold northerly winds, (b) enhances a southerly aspect. 138

17 Minimum distances between a house or greenhouse and windbreaks in order to combine satisfactory shelter with least loss of light. 141

18 Shrubs used to fill the space below heavily-crowned trees must be capable of closing the gap effectively. 154

19 An example of designs for multiple-row windbreaks used in the Rhine Valley, Switzerland (after Tanner and Nägeli). *page* 159

20 Examples of mixed composition: (a) 'line by line' mixing, each row of a different species; (b) alternate rows of tall, light-demanding trees and shorter shade-bearers; (c) mixing groups of hardwoods within a matrix of conifers. 179

21 Suggested arrangement of planting to check cross-wind gusts near cuttings on highways. (a) general view; (b) plan of arrangement. 180

22 Snow drift patterns adjacent to windbreaks of different penetrability, Czechoslovakia (after Luncz). 194

23 Windbreak designed to trap snow adjacent to a road, Czechoslovakia (after Luncz). 195

24 Windbreaks for collecting snow should have shrubs to initiate drifting on either the windward or leeward sides as appropriate. 197

25 Linking isolated blocks and clumps by new shelterbelts increases the overall shelter. 201

26 Ways through cross-wind belts may be angled or curved to keep out the wind but are liable to fill with drifted snow. 202

27 Plan of wind conditions near a shelterbelt, showing acceleration of the wind caused by a gap (after Nägeli). 203

28 An irregular profile is more effective in reducing eddying, (c), than more uniform structures, (a) and (b). 207

29 Belts with a 'pitched-roof' cross section, (a) are less effective in halting winds than belts with more or less vertical edges (b). 210

30 Examples of poplar planting in shelterbelts: (a) single-row belts of fastigiate varieties require close spacing appropriate to their habit in order to be effective; (b) broad-crowned varieties require the support of an underwood or vigorous shrubs on the edges; (c) a double row of poplars with an underwood of three rows of shade-bearing shrubs and small trees; (d) a double row of poplars enclosing secondary species in a group arrangement. *page* 217

31 Group planting in shelterbelts: (a) widely spaced groups within a matrix of another species; (b) half-groups or wedges used to fill in margins; (c) groups can be contiguous or set apart; (d) the position of groups in subsequent rows should be staggered; (e) gaps can be left around groups if desired, lines in both groups and matrix corresponding. 221

32 The flow of wind over a narrow shelterbelt and a wide forest block. 224

33 Wind abatement behind a forest block compared with that leeward of an efficient shelterbelt (after Nägeli). 225

34 Method of notch planting: (a) 'L' notch; (b) 'T' notch.
Pit and turf planting and method of planting on land ploughed by drainage ploughs. Note possible positions for planting: (a) on top of the upturned ridge; (b) on the side of the ridge; (c) on the furrow side; (d) on the furrow bottom. 233

Illustrations

PHOTOGRAPHS

1 Wind-shaped plantations in Caithness *facing page* 48
2 Horticultural shelterbelt in Switzerland 48
3 Giant lilies in Berwickshire 49
4 Single-row windbreak of cypress 64
5 Strip-cropping, using rye to shelter carrots 65
6 Swiss avenue of poplars 65
7 Snow fence in Saskatchewan 80
8 The Siberian pea-tree 80
9 Whitchester House, Berwickshire in 1881 81
10 Whitchester House in 1948 81
11 Old sea-buckthorn windbreak 96
12 Young sea-buckthorn windbreak 96
13 Flattened cereal crop 97
14 Sheltered paddocks on Pentland Hills 97
15 Old shelterbelts in Wales 112
16 Informal shrubbery as screen and windbreak 112
17 Raspberry rows can provide shelter 113
18 Espalier-trained apples 113
19 Windbreak of coir netting 128
20 Poplars, beech hedge and cypress hedge 128
21 Windbreak of *Populus tacamahaca x trichocarpa* 129
22 Windbreak of poplars and Leyland cypress 129
23 Wind-shorn tree crowns in a coastal shelterbelt 144
24 Beech and ash on a chalk bank 144
25 Windbreak in a public garden 145
26 Beech clump on a knoll 145
27 Eight-year-old four-row shelterbelt in Scotland 160
28 Windbreaks of *Caragana arborescens* 160

29 Six-year-old Swiss shelterbelt *facing page* 161
30 Eleven-year-old four-row shelterbelt 161
31 Ten-year-old four-row shelterbelt 192
32 Shelterbelt in Midlothian 192
33 Small ash group in matrix of larch and pine 193
34 Shelterbelt of oak and sycamore 193
35 Extension of hill shelter block 208
36 Shelter block of Scots pine 208
37 Larch shelterbelt 209
38 Pruned poplars 209
39 Ineffective shelterbelt in East Lothian 256
40 Derelict shelterbelt in Scotland 256
41 Rehabilitation of mixed farm shelterbelt 257
42 Improvement of worn out shelterbelt 257
43 Pine shelterbelt in Midlothian 272
44 Forestry in a Perthshire landscape 272
45 Integration of farming with forestry 273
46 Plantations for shelter and timber 273

1 Wind and Climate

Britain is a windy country, yet it would be an exaggeration to say 'windswept' in the truest sense, or to the extent that it must have been when nomadic hunters of the Old Stone Age tracked their food on the empty, treeless, tundra grasslands, which the retreating glaciers had left behind twelve thousand years ago. But, standing athwart the prevailing south-westerly winds, at the end of a long and unobstructed approach across the Atlantic, the British Isles cannot escape being called 'windy'.

Our western seaboard is occasionally exposed to gusts of wind of up to 90 or 100 m.p.h. and, in the exceptional storm of 31st January 1953, when vast areas of Holland and eastern England were invaded by a swollen sea and thousands of acres of Scottish forests were flattened by the north-west gale, gusts of up to 98 m.p.h. were recorded on the east coast at Kinloss on the Moray Firth and of up to 72 m.p.h. at Leuchars, near the mouth of the Tay. The wind touched 101 m.p.h. at Dyce, near Aberdeen.

The thirteen-year average of 261 gales a year of more than 50 m.p.h., registered in the days of the Ben Nevis observatory, tells its own story of the winds to which higher elevations are subjected. According to the *Climatological Atlas of the British Isles*, prepared by the Meteorological Office, much of the west coast experiences an average annual wind speed of 15 m.p.h. and in recent years the Electrical Research Association, in its search for potential wind-power sites, found several exposed places on the Atlantic seaboard with annual averages of more than 20 m.p.h. Along this coast the degree of exposure to high winds shows remarkable variation, particularly on the more complicated coastline of western Scotland. Here, one finds frequent examples of coastal woodlands with tall, well-formed trees, while short distances away their neighbours show crowns that are shorn and swept by the salt sea-wind.

Data of wind conditions are apt to be misleading because neither do statistics of the annual average wind speed or of the incidence of gales present the whole picture. In addition, records themselves are somewhat limited; the number of meteorological stations which maintain constant records of wind speed and direction is regrettably small and particularly so at the higher elevations. This last feature is not surprising; only a small proportion of the population of these islands lives above the 1,000 ft contour. Much of the available knowledge of local wind conditions is compiled from observations at stations without instrumental means of measuring the wind. Their figures are based on a visual assessment of the 'force' of the wind, according to what is known as the Beaufort Scale. Although it is possible with experience to gauge fairly accurately the force of the wind from its effects—for example, a wind which raises dust and loose pages and moves small branches is Force 4 (13–18 m.p.h. at 33 ft above ground), while a gale of Force 8 (39–46 m.p.h.) will break off twigs and generally impede progress—such observations are invariably made at one set time of day, commonly 9 a.m. Thus, they show only the wind conditions obtaining at that particular time, whereas the wind at ground level tends to attain its maximum speed early in the afternoon, in association with the daily temperature rise. Such morning readings are noted for their disproportionate number of 'calms'.

It is dangerous to attach too great importance to little lines on little maps, on account of the unavoidable interpolation of values between stations some distance apart on the actual ground. But, within their limitations, such maps showing isopleths of rainfall, temperature, sunshine and wind reveal much interesting, if generalized, information. A prominent feature of the wind maps for the British Isles, for example, is the general decline in average wind speed from the west coast towards the east, although there is inevitably a local rise again on the extreme east coast. This decrease in windiness, within the space of such short distances as the width of mainland Britain allows, appears even more striking in the chart of windiness compiled by C. E. P. Brooks in *The English Climate*. Based on the number of hours in a year in which the wind at a height of 30 ft above ground in exposed places exceeds 54 m.p.h. in its strongest gust, the chart shows a drop from 100 hours in Cornwall, Pembrokeshire, the Inner Hebrides and the outer, western fringe of the Scottish mainland to less than 10 hours in the southern Midlands, rising again to 30 hours on the east coast. This is due undoubtedly to the physiography of Britain and the ground configuration bequeathed to us by geological history.

Mountain systems hamper the wind, increase its turbulence and exert a frictional effect on its flow. At times they channel the wind along valleys and concentrate its flow so that the valley bottom may experience a wind force as high as that over the enclosing mountain ranges. However, their general effect is to mitigate the full force of the wind as it proceeds inland. In doing so, mountains and hills bear the full brunt on their exposed slopes; wind conditions at their summits or on the crests of ridges can be very severe. The severity increases with elevation because not only does the deflected wind accelerate towards the top of windward slopes but also high-standing peaks and ridges encounter the higher velocities prevailing in higher layers of the air. Wind increases in speed with altitude and, on a windy day, the surface wind at sea level blows at roughly two-thirds of the speed of the wind at 2,000 ft.

The wind climate of Ben Nevis (4,406 ft) is, without doubt, the extreme case in Britain but lesser hills may be much more windswept than low-lying coastal areas. This is the reason for the relatively low timber line, the limiting altitude for profitable forestry. Overseas visitors, accustomed to forests at much greater heights, find this surprising. The wind-imposed tree limit may be as low as 200 ft on the coasts but may exceed

1,800 ft in more favourablesituations in the central Highlands, until coldness sets its own boundary.

Although the frictional drag of the topography reduces the average level of the wind, it tends also to increase the amplitude and frequency of its fluctuations in speed between gusts and lulls. The gustiness factor is often of considerable importance to farmer and forester. Since an inland wind blowing at 10 m.p.h. less than on the coast may have the same gust level, the sheltering effect of land masses is somewhat smaller than might be anticipated. In this way, differences in wind conditions on the coasts and farther inland are modified to some extent as regards extremes likely to be encountered.

To return to the wind maps for the country, it is significant that only central Scotland and the English Midlands can expect an annual average wind speed of less than 10 m.p.h. This is a generalization because there will be sheltered valleys where the average is much less and upland reaches where it is considerably higher, due to the effect of relief. Nevertheless, it illustrates the importance of wind in relation to our everyday activities but especially in the pattern of husbandry. If 'weather moulds the life of man', then the same can be said of the wind in Britain. As the bringer of our weather, it is stamped indelibly on the national character and behaviour.

Though it is customary to associate a certain type of weather with a particular wind, there is no simple and constant relation between the wind direction and the kind of weather we can expect. Most wind directions can bring a range of weather conditions, according to the movement and juxtaposition of air masses, for the rotation of the earth and the distribution of land and sea have arranged for the existence of pressure zones in the atmosphere. As air masses are apt to move along certain courses, although not always, there is often a connection between weather and wind, if not a conclusive one. However, the equability of the British climate is attributable to the fact that the prevailing westerly and south-westerly winds spring from the relatively warm waters of the North Atlantic Drift, often known as the Gulf Stream. When we experience the occasional northerly polar winds or eastern winds from Siberia, the mercury falls because these winds have had less opportunity for warming in contact with the sea. If these were our prevailing winds, our winter climate would be much colder and our summers warm and dry.

The prevailing wind direction is therefore the keystone to the climatic build-up, and with the softening influence of the North Atlantic Drift mellows the severe climate to which our northerly position would otherwise entitle us. It is worth remembering that much of northern England and the whole of Scotland lies above the northern limit for practicable agriculture in continental Canada and that Labrador can be having subzero temperatures while, at the same latitude, our northern shores are registering temperatures of more than 50° F.

The moderating influence of the prevailing winds results in the annual temperature range on the west coast being more restricted than further inland, beyond the full effect of on-shore winds. Aberystwyth, for example, on the shore of Cardigan Bay, has an annual average of about 50° F, with monthly averages in winter nor lower than 41.3° F and in summer not higher than 60.7° F. On the other hand, Reading has recorded a monthly average of 39.4° F for January and 62.5° F for July. Temperature differences between the two would be understood rather better from a study of the minimum and maximum temperatures, the daily and monthly extremes and the incidence of ground frost. Late frosts in spring are common in inland areas, whereas on the coasts windiness prevents their formation except in still pockets provided by the topography.

The mildness of the winters on the west and south-west, which makes possible the profitable cut-flower industry of Cornwall and the Scilly Isles, and the many magnificent gardens scattered along the western coast-line, is given to us by a warm sea and a warm wind that has blown over it. Yet there are fewer good azaleas in Cornwall than in western Scotland, because the strong winds come when the flowers are opening in the south. But in beautiful gardens like that of Inverewe in Ross-shire and Achamore House on the tiny island of Gigha they thrive in splendour because they are sheltered from the force of the wind, not its coldness.

December and January temperatures of the Orkneys frequently parallel those of the French Riviera and rose, pansy, stock, carnation, fuchsia, sweet pea, geranium, violet and gladiolus have flowered then in the open at Balfour Castle, Shapinsay. Yet these islands in exposed places are as treeless as South Georgia or Kerguelen Island in the Antarctic, which are roughly as far from the South Pole as the Orkneys from the North. For the same reason, exposure, Herm in the Channel Islands was bare before the 1890's but now boasts stone pines, silver poplars and long-leaved eucalypts that like the mildness once the wind is weakened.

Because the general picture is one of a maritime, temperate and equable climate throughout the year as a whole, it is favourably disposed towards farming, forestry and horticulture but, since its smooth course is shattered at intervals by irregular extremes of cold, drought, heat, torrential downpour and high winds, it is not without its hazards. Of these our most constant companion is the wind. Physical damage to field and garden crops through breaking and bruising needs no elaboration. Market gardens and orchards are usually found in regions where overall temperature conditions are mild and sunny, but these are among the windiest districts in the country. So it is not surprising to find the Scillies and Cornwall a maze of hedges, walls and small enclosures, as much to protect crops against the ravages of the wind as for any other reason. Nor is it surprising to find the bulb-growers of Tiree and Coll looking for shelter. It is common on the Continent to find windbreaks erected to prevent horticultural crops being blown out of the ground by the relentless mistral.

Along our coasts, on cold wet moorlands and, again, at high elevations, the wind-flagged crowns of trees depict the buffeting action of the wind. Here, the explanation is partly the mechanical bending and breaking by the wind and particularly the prolonged drying action, which removes water from the trees by means of excessive transpiration or by shaking twigs and leaves at such a rate that roots and conducting tissues cannot replenish the supply quickly enough, often in spite of a high rainfall. The result is desiccation of buds, leaves and twigs, which wilt and die as in a drought. Windward sides suffer most and lend the trees a distorted, one-sided appearance. The height to which plants can grow is limited by their ability to transport water upward at a sufficient rate to counteract such losses. The taller the plants the more they suffer, so that the most exposed places are destitute of tree and tall, shrubby vegetation, and the woody growth that clings to some bleak hill tops is dwarfed and stunted, like the elfin woodlands of Dartmoor.

The process of dehydration of plants is a complicated affair. Briefly, a steady wind accelerates transpiration by removing the sheath of damp air which envelops the leaf; this increases the diffusion gradient from the stomata or pores to the surrounding atmosphere. Agitation of the leaves furthers the process by causing air movement within the plant cells. In a strongish wind, bending of the leaf and alternate contraction and expansion of the tissues expel more moisture. Leaves can die after a few days of vigorous shaking. Cold winds worsen the effect because chilled stems and roots are unable to absorb the water to meet the demand, particularly when the soil is cold or frozen. Flow in the plant tissues also becomes more sluggish. Often it is frost that is blamed for damage that would not have occurred without the wind. In turn, vaporization of water from the plant consumes heat and lowers the leaf temperature and gusty winds produce sharp fluctuations in temperature, quite apart from their injurious bending effects. Warm winds can be damaging too but much less so under our normal conditions of intermittent sunshine, when a warm wind is often welcomed.

Wind deformation of trees is not necessarily a qualitative or quantitative indication of the windiness of an area, the degree of distortion being considerably affected by local soil conditions, especially moisture availability, aeration and fertility, and by sea spray and atmospheric pollution. However, it demonstrates some of the more extreme effects of wind desiccation on that particular site. Though less striking, wilting of crops under a constant wind is common. In 1958, the winter-green Welsh hills, by March shooting out a fresh bite for sheep and early lambs, were suddenly shrivelled brown by a spell of cold dry easterly winds. Only sheltered strips by hedges offered pickings for the unfortunate sheep, and in some areas the effect was distressing.

Even before wilting occurs, the loss of water from the plant checks carbon assimilation and, as respiration continues, the plant eventually starves. The stronger the wind, the worse the aggregate effect. Although the water loss from individual plants may not show a proportionate rise with increasing wind speeds, it is easy to see in young cereal or grass crops that, whereas light breezes no more than skim the surface, stronger winds penetrate deeper and expose greater leaf areas to drying.

Because of the need for shelter, there have been attempts throughout the ages to modify a local environment, or find another more suited to a particular purpose, or provide some form of insurance against the worst of the risk. Many villages have been sited where the land formation offered protection against the wind and the lee slopes of Cardiganshire hills hold numerous small farms and cottages tucked away from the blast. In the course of time, woodlands, hedges, shelterbelts and scattered clumps of trees have reduced the exposure factor on many farms, if mostly unintentionally. But in market gardens, nurseries and orchards, the arrangements for wind protection as well as against frost and sun have been deliberate, often elaborate and costly, though obviously an economic proposition. Similarly, it is due to the sheltered situations, natural or man-made, away from the blasting effect of wind, rain and salt, that the exotic gardens of the Atlantic seaboard prosper.

Many parts of the world have similar problems. While the temperate regions depend upon westerly winds for rain, in the same way that east-facing tropical lands rely on the trade winds and the Indian and Burmese farmers in May await the abundant moisture of the south-west monsoon, a lot of prevailing and local winds are less welcome. Fearfully hot winds, like the sirocco in North Africa, the khamsin in Egypt and Palestine and the violent summer winds across Persia, scorch and shrivel unsheltered crops and raise tremendous storms of dust and sand. Cold dry winds, such as the mistral in Provence, roaring down the Rhône valley, tearing up crops, robbing soil and plants of moisture and twisting trees to the south; the tramontana which ravages northern Italy; and the bora which spreads intense cold from the Balkans over the Adriatic in winter, are all disastrous to vegetation. The north wind in Switzerland, famed for its blizzards and spring frosts, chills the ground, withers field crops and makes orchards impossible in some districts. Even the southerly föhn which, dried as it passes over the Alps and then strongly warmed as it rushes down the northern valleys, melts the snow and brings a sudden flush of spring to many sunless aspects, where orchards and crops depend upon it, has its unfavourable side. Later in the season, it flattens crops and uproots trees and makes windbreaks essential. Like the Rocky Mountain chinook, which pushes the limit of cultivation further north in Alberta and western Saskatchewan, it has a beneficial influence, but there is also a fierceness to the föhn that is absent from the chinook.

It was the combination of cold Arctic winds and the strong flow of air from the Siberian upland that led to the early nineteenth-century attempts to improve the climate of the forest steppe and black soils in western and central Russia. The winter snow cover was blown off the open fields and dry winds drew moisture from the bare soil, impoverishing the meagre reserve necessary for spring sowing. In summer, hot dry winds from arid lands to the south brought periodic droughts and crop failure. Counter-measures culminated in the 1948 Stalin Plan for the Transformation of Nature, a vast afforestation project destined to cover 15 million acres with trees to shelter near 300 million acres of farmland. The idea that man could control and regulate the basic climate and thereby dominate Nature was implicit in the plan.

But one cannot change the overall environment, as this is dictated by factors outside the range of human interference. Climate on a large scale—macro-climate, as it is often called—changes only when there is an alteration in atmospheric circulation or in the degree of incoming radiation from the sun or if there are major changes in the earth's surface features. It is only the minor surface characteristics that can be altered by human activity and then not on such a scale as to affect the weather. If deserts were to replace vegetation in continental land masses, cool moist winds would likely be exchanged for hotter and drier winds, but otherwise the scope for change is small and confined to the lower layers of the air, where, locally, it may be significant to the farmer and gardener.

The Russians were not alone in thinking that the large-scale climate could be controlled. A petition appeared in the United States in 1866 to 'afforest the plains and improve the climate' and the 1873 Timber Culture Act seems to have been backed by the belief that if settlers were encouraged to plant trees in the Great Plains, rainfall would increase and defeat the droughts. Later, it was claimed that the spread of cultivation had increased rainfall, through promoting absorption by, and subsequent evaporation from, the soil, so raising the atmospheric humidity and producing precipitation. The same idea that trees could increase rainfall may have helped, if not actually activated, the introduction of the Great Plains Shelterbelt project by Roosevelt in the 1930's.

But forests have no appreciable effect on total rainfall. Theoretically, blocks of tall trees force rain-bearing winds upwards to release more moisture, while the highly saturated air above forests may just tip the balance in favour of a local shower, which would otherwise pass by. Such differences are hard to measure and even harder to analyse. Within the range of sea and mountain mists forests certainly intercept more rain than does low vegetation; but, inevitably, there is increased evaporation from the crowns afterwards. To say unequivocally that afforested Welsh valleys or Scottish glens experience more rain than those unplanted would require a formidable array of equipment and years of observation, since rainfall figures fluctuate over long periods. However, it is reasonable to suppose there are more misty days around the forests.

The value of forests lies more in regulating the output of water. Trees intercept the rain, cushion its impact on the ground and curb its erosive tendencies; the spongy forest floor and root penetration help absorption and percolation downwards and the surplus ground water is released gradually to rivers and streams. In comparison with bare soil or grass, trees consume more water in transpiration and wood formation. Against this, their longer roots tap water deep down in the ground. Trees hold the rainfall, bind the soil, and give the land the best value from the water it receives. In less moderate climates erosion moves in when the forests are devastated; wind and sun attack the exposed ground and turn heavy rains into an enemy of the soil. Forests do not give the rainfall necessary to grow crops; they merely conserve the supply and safeguard the soil. Strips of plantation that allow more space for cropping also improve the water balance and shield the soil; as distinct from checking run-off and water erosion and holding great quantities of water in reserve underneath the forest, the climatic effect of forests and plantations is one of shelter.

Any obstacle which obstructs the flow of the wind creates a zone of shelter nearby, mainly on the leeward side, but to a lesser extent on the windward side as well. Owing to the wind reduction, a local or micro-climate arises in the sheltered area and, as anyone who has taken shelter against the wind will know, this is very different in character from the feel of the climate where the wind has full play. It is the climate near the ground which is altered and, on balance, improved. When the obstacle is a shelterbelt or other form of windbreak, breaking

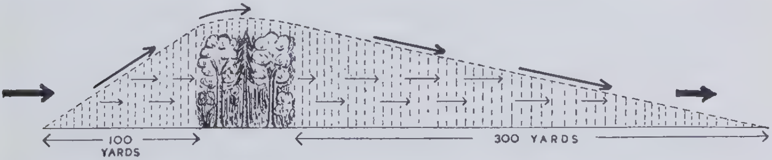


Fig. 1 A 30-ft high shelterbelt affects wind speed for 100 yards in front of the trees and 300 yards down-wind.

the force of the wind across a broad front, the ground environment is changed over an appreciable area. In simple terms, the wind is abated over a distance equal to about forty times the height of the barrier, a quarter of the protected area being on the windward side and three-quarters down-wind of the barrier. The wind gradually resumes its unobstructed pattern, so that at the end of the sheltered zone any reduction in wind speed, i.e. shelter, tapers away.

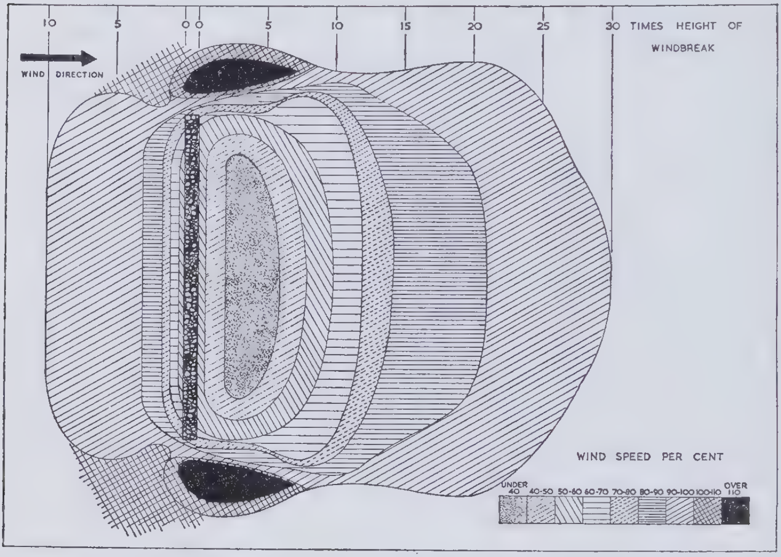


Fig. 2 Plan of wind conditions in the vicinity of a moderately dense shelterbelt. Wind speed expressed as a percentage of the free, unobstructed wind.

The extent to which these local retarding effects on the wind accumulate, where a series of shelterbelts, hedgerows or other barriers that check the wind is spread over a large area, has been the subject of much speculation and experiment. It was once thought that parallel belts, planted one after the other across the path of the wind, would progressively reduce its velocity. In fact this does not occur. A rock lying on a river bed does not affect the rate of flow very far downstream and, if the water is deep, the ripple dies away before it reaches the surface.

So it is with a shelterbelt which is only obstructing the air flow in the very lowest layers of the atmosphere. The pattern of shelter behind the second and subsequent windbreaks is little different from that behind the first. Each barrier acts independently of the others. Where wind-tunnel studies employing model windbreaks have detected a small cumulative effect on wind speed immediately behind the second of two parallel screens, this has quickly disappeared further down-wind, and is barely discernible under outdoor conditions where the natural wind is in any case more disturbed than the flow in a tunnel.

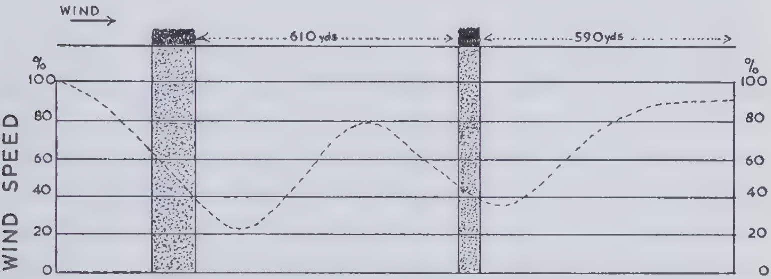


Fig. 3 *Parallel belts have no apparent cumulative effect on wind abatement (after Nägeli).*

Nevertheless, it is possible to plant shelterbelts sufficiently near together to ensure that their zones of shelter overlap and that the free wind speed is not resumed at any point in between.

Wooded landscapes, however, have less wind than more open country nearby. The virtually treeless, true prairie grassland of Saskatchewan, now mostly cultivated, has, for example, an average wind speed ranging between 12 and 16 m.p.h. On the other hand, the broad band of aspen grove country or park belt that separates the real prairie from the northern forests has a corresponding average of 9 to 12 m.p.h., due to the clumps or 'bluffs' of aspen that are scattered liberally over the gently undulating plateau. In the northern forested lands the wind speed falls to 5 to 9 m.p.h., because of the greater frictional drag exerted by the tree cover.

Changes in a westerly wind during its passage across Jutland have been studied by a Danish engineer, Dr Martin Jensen. He found that the wind blowing across the centre of the peninsula, which is well-wooded, well-hedged and more varied in topograph than the southern districts, is much reduced in velocity by the time it reaches the east coast in comparison with the wind across the sparsely wooded, thinly hedged and more open south Jutland. This suggests that landscape features tend to exhaust the energy of the wind and reduce its speed. But the wind over the wooded landscape is not permanently abated by the time it reaches the other side. Being no longer hampered, it blows no less vigorously than when it first came into contact with the trees. Although shelter plantations within an area affect the wind in that area, once out of the planted region the energy lost by the wind through frictional effects within the lower levels of the atmosphere is easily and quickly replenished from above. The basic wind at 2,000 ft above ground is unaffected by surface features, which sometimes accounts for a difference in direction observed between cloud movement above a valley and the wind at ground level. Therefore, a wind that has passed through a wooded region suffers no lasting and significant change in its velocity level. The decrease in windiness between the west and east coasts of Britain, important though it is to the country's climate, is quickly lost again over the North Sea.

At the same time, there is plenty of support for the idea that the general wind climate at the ground, where it really matters, can be altered by widespread plantations on formerly exposed terrain, in so far as the area itself is concerned. This was the Russian object and, to a certain extent, the American aim also. But the wide Russian barrier belts, which were expected to check the wind permanently and shelter enormous areas, are now known to have no greater effect than a single narrow windbreak, and a few hundred yards away the wind blows as strongly as before. The secret of success lies in the number and distribution of shelterbelts throughout the region to be sheltered, not in their width.

When the wind encounters a barrier such as a shelterbelt or windbreak, its uniform current is disturbed and the turbulent motion exerts a brake on the forward velocity. A cushion of slow-moving air, banking up on the windward side of the obstruction, accounts for the shelter that exists close to the exposed side of a wall or windbreak. The major part of the hitherto horizontal air stream is deflected over the top; the remainder, in a much weakened form, passes through the 'cushion' and the barrier, unless the latter is too dense for this to happen. The ideal shelterbelt filters the wind without attempting to block it completely and the air that passes through the belt emerges on the leeward side at a slower speed, preventing the air forced over the top from sweeping down to the ground and resuming its normal pattern until some distance down-wind. Thus arises the zone of shelter that can be of immense value in exposed districts.

Dense, impenetrable barriers divert the whole force of the wind over their tops, apart from small losses of kinetic energy used up on impact. This concentration of pressure is sucked down a short distance behind the windbreak, allowing the wind to resume its unhindered progress relatively quickly and producing a shorter range of shelter. But it can also cause vigorous eddying, which frequently flattens cereal crops behind a dense block of woodland or damages plants at the back of a wall and occasionally overthrows trees on the leeward edge of a thick plantation. Apart from this harmful eddying, the wind behind a dense windbreak falls more than in the lee of a more penetrable barrier but the shelter effect peters out more rapidly. Because of the greater range of protection and the smaller chance of dangerous eddying, the moderately dense shelterbelt is preferred for protecting field crops and sheltering a reasonable area of ground. In this case, the greatest degree of wind abatement occurs not immediately behind the trees but between two and four times their height down-wind. From this point of minimum wind there is a gradual acceleration until the wind regains its former speed.

The denser type of belt, allowing less wind to flow through it, has its uses where draught-free shelter is wanted to protect

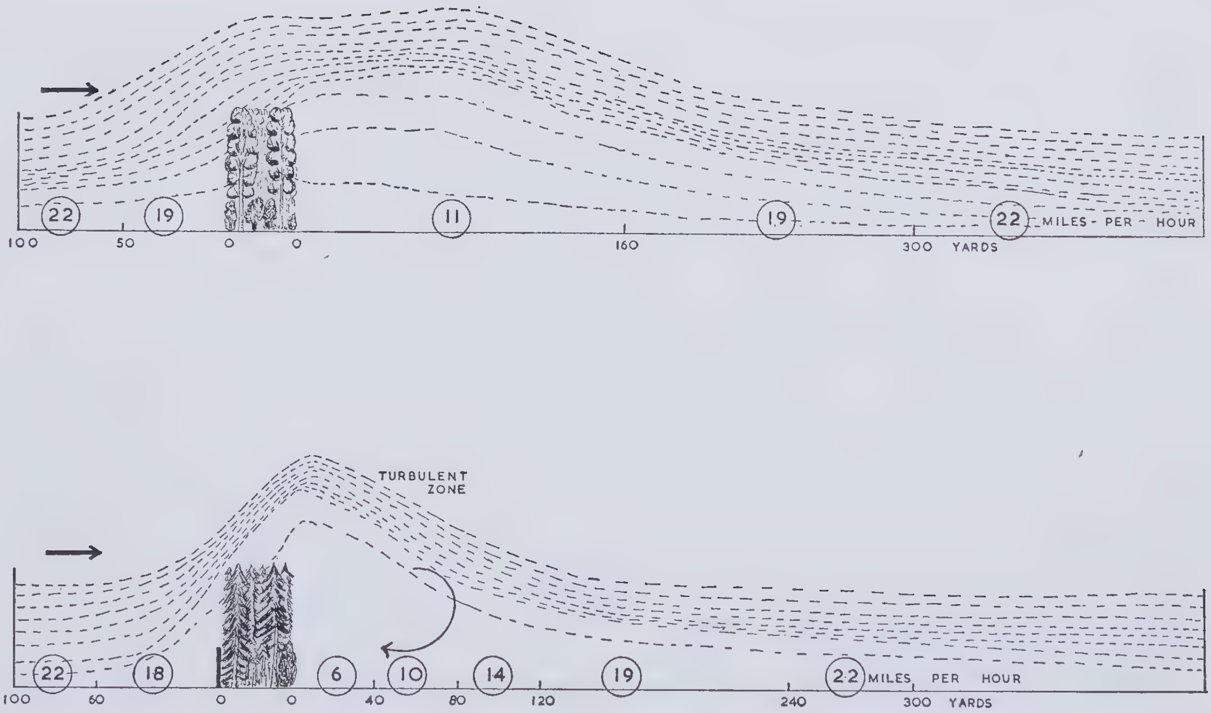


Fig. 4 *Effect of (a) moderately penetrable and (b) dense windbreaks on the flow of wind. Figures circled denote approximate wind speeds in the various sections. Horizontal distances (in yards) refer to windbreaks 30 ft tall (after Kuhlewind, et al.).*

livestock during storms. The range of shelter is then of less interest than maximum protection close up to the belt and the very dense shelterbelt gives the lowest wind velocity on the leeward edge or within the belt itself, not some distance away.

Thin and open belts offer little resistance to the wind, which sweeps through comparatively unhindered. Sometimes funnelling or jetting of the wind between the trees causes a marked acceleration on the margins and under the trees; the wind there often blows much more strongly than in the open, far beyond the influence of any shelterbelt. Similarly, belts that are more open at the bottom but dense amongst the crowns let cold draughts sneak through to become a source of danger to cattle and sheep seeking shelter on the leeward side. Open shelterbelts, like hedgerow trees, hamper the wind but the reduction in its speed occurs comparatively far down-wind and is usually cancelled out by the stronger winds near the trees and the fact that the total shelter produced is of little consequence.

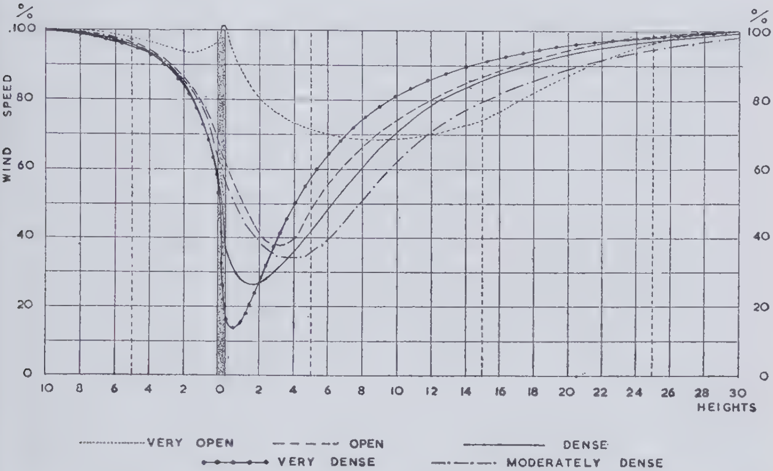


Fig. 5 Patterns of wind abatement in the vicinity of shelterbelts of different density (after Nägeli and Caborn).

The range of shelter effect, the distance over which the wind is slackened in speed, is determined primarily by the height of a shelterbelt or windbreak and secondly by its density. But the quality of the shelter or the amount of wind reduction is controlled by the density of the structure, i.e. its relative permeability to the wind. In addition, the lie of the ground modifies the influence of a shelterbelt: ground that slopes away to leeward increases the range of protection, while a rise behind a belt shortens the reach of the shelter.

Different densities of shelterbelt therefore produce different patterns of wind reduction, according to the amount of wind they let through. Typical values for the relative wind distribution near shelterbelts in five density classes are given in Table 1; these are expressed as percentages of the normal, unimpeded wind prevailing at the time.

TABLE 1

WIND SPEEDS NEAR 30-FT HIGH SHELTERBELTS OF DIFFERENT DENSITY

DENSITY OF BELT	WIND SPEED AS A PERCENTAGE OF THE UNOBSTRUCTED WIND SPEED											
	At Distances to Windward of Belt of (yards)			*Within the Belt*	*At Distances to Leeward of the Belt of (yards)*							
	100	50	0		0	20	50	100	150	200	250	300
Very open	100	98	94	96	102	80	72	69	74	86	97	100
Open	100	96	70	75	60	40	48	75	87	95	99	100
Medium	100	96	65	62	55	37	36	60	77	89	95	100
Dense	100	96	55	—	40	27	42	70	86	94	97	100
Very dense	100	95	55	—	15	27	58	82	91	96	99	100

(*A distance of* 10 *yards is equivalent to* 1 *'shelterbelt-height'*)

The effectiveness of individual shelterbelts, their ability to check the wind and afford shelter, exhibits wide variation. The figures above are approximate averages based on actual wind measurements adjacent to a large number of belts so that there are shelterbelts that give better results than the best shown in the table and those that provide less shelter than the poorest category above. However, what is important is that these figures are a guide as to what can be expected of a shelterbelt and, moreover, these percentage reductions in the wind hold good for winds up to 25 m.p.h. at least, with only minor differences due to the nature of the wind and weather conditions. But what these wind reductions mean in terms of shelter value is less constant; this depends on the strength of the wind at any particular time. The wind's energy varies roughly according to the cube of its velocity, so that even a small decrease in velocity becomes more significant when considered in terms of the wind's power to cause damage. Reducing the wind speed by a quarter more than halves its energy or force.

It is customary, however, to adopt some criterion of useful shelter under average conditions and this is often regarded as a 20 per cent abatement of the wind. In this way, a moderately dense shelterbelt, 30 ft high, provides useful shelter for 20 yards to windward (2 'shelterbelt-heights') and for 150 to 200 yards leeward (15 to 20 heights), whereas a very dense belt of similar height gives little shelter beyond 100 yards (10 heights) on the leeward side. Clearly, there is an optimum density for a shelterbelt structure and this has been found experimentally to be about 50 to 60 per cent, i.e. the degree of permeability to wind should be about 40 to 50 per cent. In other words, when looked at from the front, the mesh of leaves, branches, twigs and trunks that makes up the belt should cover 60 per cent of the total frontal area. This 'porosity' or permeability is best distributed fairly openly throughout the entire height of the belt without more openings in the crown space than amongst the tree stems

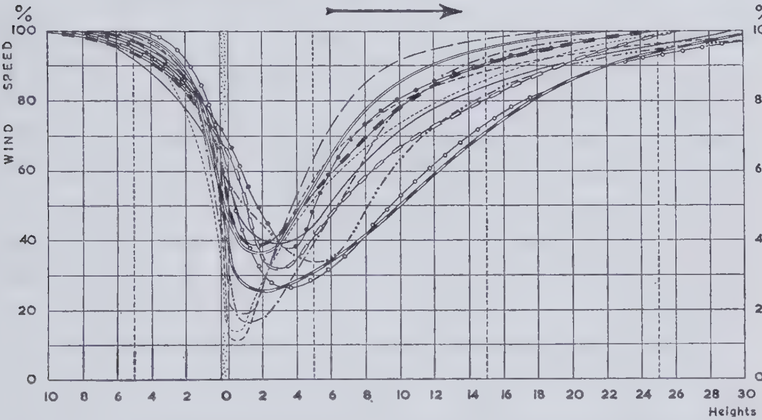


Fig. 6 *The ability of shelterbelts to check the wind and afford shelter exhibits wide variation (after Nägeli).*

or *vice versa*. But for most purposes it is better for a belt to be on the dense side towards the ground than to be more open. Keeping the stem space relatively open so as to achieve a better distribution of snow on the leeward side is an exception.

Translated into terms of trees and planting distances, this ideal density depends on the shelterbelt width and the branching habit of the species used as much as upon the number of trees planted per acre. So that narrow shelterbelts, carefully constructed, can afford as much shelter as wider belts of the same overall permeability and save on land and trees.

Climatic factors being closely linked one with another, when the wind is lessened air and soil temperatures and humidity tend to increase. Water losses from plants and soil through evaporation and transpiration fall and the moisture reserve in the soil is thereby enhanced. In turn, these small changes in the heat and moisture economies of air and soil are transmitted to the growing plant. The environment or local climate becomes more amenable to vegetative growth as well as more comfortable for the grazing animal.

Day temperatures in sheltered areas, for example, are usually higher than in the open, because of the reduced heat loss to higher levels of the air through wind disturbance, and because less heat is consumed in evaporating moisture from plant and soil surfaces. Temperature changes vary with the weather and are never more than two or three degrees, or found much beyond 10 shelterbelt-heights down-wind. Nevertheless, they can be significant in extending or intensifying the growing season, giving an early start to crops and hastening ripening.

The incidence of wind-frost, brought by extremely cold wind from the Continent or polar regions, is reduced within the protection of shelterbelts but cold air dammed in sheltered fields on clear, still nights aggravates the danger of radiation frost. Dense belts, for this reason, are not recommended for protecting crops sensitive to frost; permeable belts allow the air to filter through and maintain the circulation which prevents stagnation. Air that is completely stilled settles in layers, the heaviest and coldest at the bottom where the worst damage to ground crops occurs.

Atmospheric humidity, being dependent on temperature, wind, water loss from plant and soil, as well as on the weather and time of day, may rise 2 or 3 per cent near shelterbelts. Its influence on evaporation and transpiration effects a moisture saving which is of immense value in dry-land farming or during particularly dry spells in temperate climates. Reduction in evaporation means also a reduction in heat loss; the sudden drop in temperature following a summer shower is due to heat being consumed to vaporize the moisture. Evaporation, as a function of the wind speed, is also affected directly by a reduction in the wind as well as indirectly through the wind's influence on humidity and, generally speaking, it follows approximately the same pattern as wind abatement near a belt.

Snow accumulating near windbreaks raises the moisture level in the soil, especially important in semi-arid, continental regions, and to this is added the greater dewfall that shelterbelts encourage. The temperature of the soil is raised because more warming of the surface takes place in shelter and this heat can be conducted downwards. Conduction is increased by moderate amounts of moisture in the soil and reduced evaporation from the surface again means that more heat is available for transporting to lower soil layers. Even a slight screen two or three feet high can raise the temperature of a plot by as many degrees in early spring, except in the early morning when it casts shade, through checking a cold, north-easterly wind.

The shelter that lies behind a belt of trees or an artificial windbreak is therefore more than a drop in the wind. It is, in fact, a very different climate as far as animals and crops are concerned from that where the exposure is unbroken. The pattern of plant growth reflects its environment, the properties of which are passed on to the plant as growth factors. Similarly, the animal's environment affects its metabolism, its comfort, resistance to disease and general well-being. Improvements in environment can accordingly be turned to profit in farming and gardening but there are also other directions in which shelter can be put to practical advantage.

2 The Value of Shelter for House and Garden

Winds howling around houses exposed to the coasts or on open plains or high in the hills fill many a winter's night with strange noises. Streaming over cavities in rocks and buildings, setting the air inside vibrating, they incite an extraordinary range of sounds, from the thin whine of shells on the sea-shore to the low roar of caves in the mountains. On still, cold nights when polar air sweeps southwards, telegraph wires hum with even monotony as the wires contract and tension increases, setting up a harmonic rhythm; in a gale they sing and shriek, due partly to the whistle of hollow insulators, partly to the resonant throbbing of the wires as the lashing of the wind plucks at them first from one direction and then another.

Eddies which round corners and roll over gables, first clockwise and then unwinding with astonishing rapidity as the gusts rise and fall, can wreak havoc in a garden. A good screen of trees in the right quarter can break or divert the wind, protecting shrubs and herbaceous borders and moderating the worst of these noises. The whoops and thuds of the strongest gusts that seem to shake the very foundations will give way to the threshing of tree branches and, in more quiet moments, to the humming of twigs and high-pitched rustlings or forest 'murmurs' that are always there to some extent, even with the slightest breeze.

This is mainly a winter problem, since the worst gales come in winter, usually from the north or west. But more than the noises of the wind and the irritating rattle of doors and windows, there is the question of domestic comfort. Frequently, the rooms on one side of a house are unpleasantly cold, sometimes unbearably so, because a strong wind is blowing from that direction. Cold winds mean lower standards of indoor comfort, or higher fuel bills, or both; so that the shelter of a house should cater not only for winter gales but also the biting winds from north and east.

The windbreaks that screen farmhouses on the North American prairies are so much the general rule that they leave no doubt as to their usefulness. Some years ago, more than five hundred farmers placed their annual saving on fuel due to the shelter at an average of sixteen dollars. The tall, narrow, close-clipped hedges of beech and hornbeam, common in the Eifel Mountains of Germany, are sometimes as high as the houses they protect and often so close that door and window openings have to be cut in the wall of foliage. Again, in windy parts of France, houses curtained off by cypresses testify to the keenness of the winter climate. It is also true to say that many plantations around the seats of Scottish lairds were not planted merely for adornment.

Experiments with test houses in the United States, where indoor temperatures were maintained at 70° F., show that a windbreak on the north saves more than 20 per cent of the fuel consumption, a figure confirmed by examining houses in four separate localities where such shelter was provided. With protection on three sides of a house, savings may run as high as 30 per cent. For an annual coal consumption of ten tons, this means a saving of two to three tons a year. Until similar studies are conducted in Britain, economies to be achieved in heating costs through providing shelterbelts to temper the cooling winds to exposed houses are a matter for conjecture. Winter temperatures are considerably higher than in the middle of the North American continent and there is a preference for lower indoor temperatures than would be considered comfortable across the Atlantic. On the other hand, we lack the winter sunshine that helps to heat American houses, whilst tradition, slow to die, keeps the minimum number of rooms at tolerable temperatures. Much heat that is generated escapes through inefficient methods of heating and insulation and the over-rated addiction to 'airing' rooms. Yet it can cost less to heat an old, stone-built house in a sheltered situation in the north than a much smaller, brick house in a mild locality by the sea far to the south, if the latter is fully exposed to high winds off the sea on the west and to the sweep of easterly winds at the rear.

Early in 1958, the House of Commons heard a surprising estimate of the amount of coal that could be saved if our buildings were efficiently insulated. Putting a shelterbelt round a house or farm building is akin to adding a layer of insulation, because still air is trapped within and behind it. A cellular blanket or thatched roof employs the same principle: air is a poor conductor of heat. It is when the air is moving that heat is quickly carried away.

Greenhouse owners anxious to keep a winter temperature around 40 or 50° F are very conscious of fluctuations caused by changes in the wind and of the battle to maintain the heat when the wind lies in the north or east. An increase in wind speed from 0 to 20 m.p.h. roughly doubles fuel consumption, and many have come round to the idea that a good hedge or screen on these sides can cut heating costs by 10 or even 15 per cent. Inner shells of polythene sheeting in some of the larger glasshouses producing winter blooms reduce the space to be heated and add insulation. Wire netting, strung between ridges, is claimed to be effective in adding insulation, presumably because wind movement against the glass is reduced. Besides saving on fuel there may be other advantages: a Swiss market gardener, with a five-year-old shelterbelt of poplar, alder and birch, then 18 ft high, protecting a large glasshouse, claimed some years ago that for the last two seasons tomatoes had ripened two weeks earlier than usual and secured a better price on the early market.

The main fear in planting windbreaks near glasshouses is that they may restrict the light, but this can be overcome provided there is space available to plant near enough to check the wind but not so near as to obstruct illumination. Ideally, a glasshouse needs to be sited where the wind is at its lowest level, which means 50 to 100 ft behind a moderately penetrable windbreak, 20 ft high, i.e. between 2½ and 5 'heights' downwind. But at this distance there is still a risk of shading in winter months when the sun never gets very high and shadows are long. It has been suggested that woods or rising ground, whilst affording appreciable wind protection, should not be more than 10° above the horizon to the north of a glasshouse or more than 5° to the south, east or west, which would imply windbreaks at least six times their height away on the north and twelve 'heights' away on the other sides. A compromise is required; some sacrifice of light is a modest loss compared with the ruinous fuel bills that may be caused by long spells of cold winds. Light can be supplemented artificially much more cheaply than heat, and the fact that many greenhouses on plant-breeding and horticultural stations have hedges and shelterbelts fairly near suggests that shelter against wind wins on balance. There is always the possibility, of course, that more greenhouses are sited for convenience than for efficiency of either illumination or temperature.

Given the height and orientation of a shelterbelt, the length of its shadow can be calculated from the following formula:

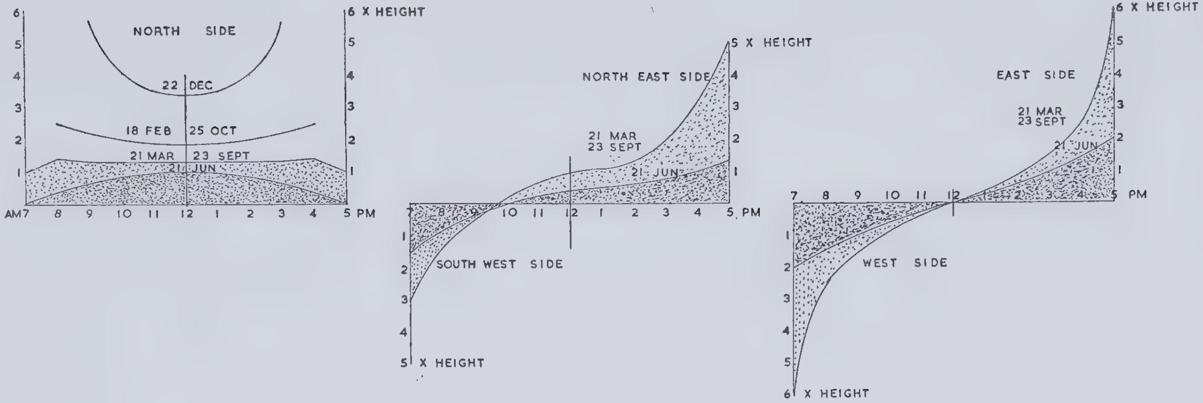
$$L = h.\ \sin\,(180 - \beta + \gamma).\ \cot\alpha$$

where L = length of shadow;
h = height of shelterbelt;
α = altitude of sun;

$$\left.\begin{aligned}\beta &= \text{azimuth of sun;}\\ \gamma &= \text{direction of shelterbelt}\end{aligned}\right\}\ \text{measured clockwise from north}$$

But what this means in terms of reduced heat and light has evaded measurement up to the present. Applying this formula, W. H. Hogg of the Meteorological Office has shown that in the south of England (latitude 50° N) a windbreak 10 ft high, running east to west, causes little loss of sunshine provided the greenhouse is 40 ft away. The loss amounts to about an hour at the beginning and end of the day in mid-winter. With a north-south windbreak of this height a good deal of sunshine is lost in spring and autumn as well as in winter and 60 to 70 ft from a windbreak is a better site for a greenhouse. The best distance may depend on the time of year when maximum lighting is most desirable for at the spring and autumn equinoxes (21st March and 23rd September) the north side of an east-west shelterbelt has a shadow zone only about 1.3 times the height of the trees and at mid-day in mid-summer no more than half the height of the belt. A screen running from north to south creates no shading at mid-day but in spring and autumn the shade extends to 6 'heights' at 7 a.m. and 5 p.m. on the west and east sides respectively, although at mid-summer the shadow is no more than 3 'heights' wide. Windbreaks orientated from the north-west to south-east to counter the prevailing south-westerly winds cause much shading in their lee at the close of a winter's day, when the shadow reaches to 9 'heights'; this falls to 5 'heights' at 5 p.m. in spring and autumn, to 2 'heights' at 3 p.m. and only exceeds 1 'height' towards 5 p.m. in summer. Naturally, shadows are longer in more northerly latitudes.

Assuming that a shelterbelt is to protect a greenhouse at a distance of 4 to 7 times its height further down-wind, the structure must filter the wind and not be so dense as to give the greatest drop in the wind close to the trees. Inevitably, the wind speed near the ground will be less than at the height of the ridge of the greenhouse but investigations in Switzerland have shown that both penetrable and dense screens reduce the wind at levels well above their own height and measurements near a hawthorn hedge, carried out by N. E. Rider at Cambridge, have confirmed this. Rider found a considerable effect on the wind at 2 m. above ground, although his hedge was only 1.68 m. high. For shelter well above ground, the Swiss studies seem to favour the denser type of windbreak so that belts to protect tall glasshouses can be denser than belts intended to shelter ground crops, provided the minimum wind speed is obtained a short distance from the trees. A too-solid structure will be in danger



(*a*) (*b*) (*c*)

Fig. 7 *Guide to the shading effect of windbreaks running (a) from East to West, (b) from North-West to South-East, and (c) from North to South. Shadow lengths expressed in multiples of windbreak height,* H, for latitude 50° N.

of producing eddying that will extract heat from the greenhouse rather than maintain it.

A further advantage of shelter for greenhouses and areas under cloches is the reduction of breakage. Stretches along the Sussex coast, for example, although otherwise eminently suitable, find glasshouse cultivation too risky a venture because of high winds. The higher the wind pressures likely to be encountered, the smaller the size of panes that can be fitted, which in turn means a reduction in the light they admit. But this problem is not nearly as serious as the high vulnerability of cloches during gale-force winds. Windbreaks in this case are needed more as an insurance against heavy losses than to improve conditions beneath the cloches.

Commercial horticulturists need no reminder of the havoc wrought by a few hours of blasting wind. An acre of spring flowers or early vegetables, torn and twisted by the wind, with foliage and flowers browned and scarred, involves a major capital loss as well as a loss of income. On light soils where an eroding wind tears up onions and beetroots, leaving the young plants shrivelled and spent in the furrows but still pounded by particles of peat or sand, damage can be catastrophic. It is not surprising, therefore, that measures of wind protection in some gardens and nurseries are elaborate; the capital tied up in screens and wind barriers is a significant part of the total investment.

Private and markèt gardens near the sea have the additional problem of salt spray. Though the worst damage is confined to a coastal belt three or four miles wide, occasional storms penetrate further inland. Injury to vegetation takes the form of scorching along leaf margins and veins and burned blotches where the concentrated spray droplets dehydrate the tissues through osmotic pressure. Winter buds suffer, damaged twigs die back, and injured leaves fall prematurely in the autumn. Plants with hairy or thick, leathery leaves often escape harm but delicate, glabrous leaves like those of lettuce suffer acutely.

Spraying sea water on plants rarely produces the same effect.

Salt spray, the nature of the wind off the sea and its temperature are collectively involved in causing the damage. On the Welsh coast, some of the worst salt storms spring from the north-west, associated with fast-moving, cool, dry air that has an extraordinary capacity for whipping up spray and carrying it considerable distances. A late September storm will rapidly scorch field hedgerows and gardens, attacking fairly resistant species like blackthorn, willow and elder and bringing an early autumn. Even shoots of *Escallonia punctata*, normally immune, can be left limp and blackened in a couple of hours.

Market gardeners are concerned with shelter to some extent or other all the year round but for most domestic gardens it is the spring and summer which matter most, although safeguarding tender shrubs and perennials through the winter is also important. Draughty corners, where the wind sweeps round the side of a house or garage, often present problems. The average suburban and country garden with hedge or fence is not exposed in the sense of an open field or large commercial horticultural unit. Therefore, it is not usually a case for replacing hedges with taller windbreaks, which might in any case be un-neighbourly on account of shading on the other side. But built-up areas are unavoidably draughty; air must move in to replace that forced to rise by the heat from factories, offices, shops and domestic chimneys, making surface winds in towns extremely variable and strongly gusty. Deploying low hedges or clumps of shrubs and small trees, even alternating strips of high and low crops in the vegetable garden, in such a way that they screen the more windy spots and the more sensitive plants and form natural sun-traps, may be sufficient to halt the draughtiness.

Walls afford good protection so long as the wind is light and steady, but a gusty wind will eddy round the inside and, if cold, will quickly displace the warmer air of the interior. Plants near garden walls then experience sudden changes in temperature which may be injurious when the wind is particularly chill.

Taller windbreaks on the north side of a garden are especially rewarding but it may be less desirable to repeat them on the other sides unless ample room is available. It is the larger garden which can make use of relatively high shelter on the east, west or south, not those which are 100 ft or less across.

The advantage of such wind protection, provided the frost risk is kept in mind, lies in earlier warming-up of the soil, earlier flowering and fruiting, a reduction in wind damage to shoots, blooms and blossom, and in the greater variety of ornamental shrubs which can be cultivated. Shelter against the wind, more than any other single factor in our climate after frost, dictates the range of exotics which can be grown.

Frost is, without doubt, the gardener's major enemy. With an irregular beginning and end to our growing season, often punctuated by frosts, sheltered spots are apt to suffer. There is little or no wind on the clear nights that bring radiation frosts, when heat radiates strongly from the ground and an inversion of temperature occurs, but windbreaks can curb what little circulation exists. Thus, the incidence and intensity of ground frost can be increased. When an absolute calm prevails everywhere in the vicinity, windbreaks cannot aggravate the risk of damaging frost but dense barriers need always to be avoided in situations inclined towards frostiness. In some gardens, tall shelterbelts are left rather open at the bottom for this reason.

Tall belts of trees may protect crops on their margins on still, radiation nights because they shut off part of the sky and reduce the heat loss. But in the case of the wider belts, cold air flowing down from the tree crowns may offset the advantage. Frost may then last longer in the shelter because of the slower mixing of air as it begins to warm during the day, which is further evidence against using structures that are dense. Many Dutch bulb growers maintain that hedges on level land extend the frost period each day after a frosty night but shelters that seem barely sufficient to break the wind at other times of the year usually escape criticism because they allow the maximum ventilation during periods of frost.

Frost flows like a river, cold air draining down slopes and forming still pools at very low temperatures in hollows and valley bottoms. Differences in temperature up to 12° C. have been recorded for differences in elevation of only 145 ft in Germany.

Gardens in such situations are vulnerable and those on flat, valley land can do little to alleviate the problem, beyond having high walls to keep out the katabatic drainage. Many old walled gardens in Scotland at the foot of slopes have higher walls at the top, both to catch the sun and prevent frost from flooding the garden. Such a garden has then to fear only the cooling from its own area, greater of course on sand than on clay, but since humidity tends to be higher due to the surrounding shelter this exerts a check on outgoing radiation. Scattered trees which screen off part of the sky have a similar effect.

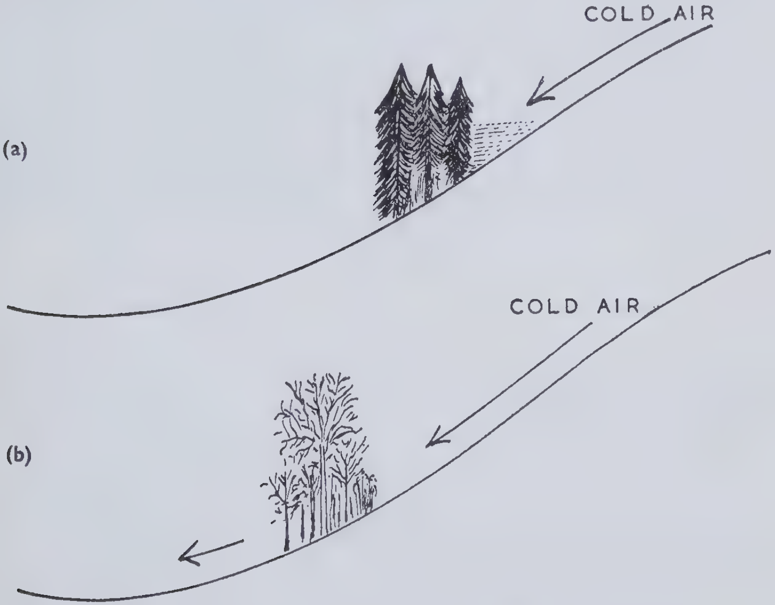


Fig. 8 *Dense windbreaks (a) create frost pockets. Penetrable windbreaks (b) allow cold air to drain away and are important at the foot of sloping gardens and orchards.*

The problem on slopes is to reduce the catchment area for cold air or to use dense windbreaks or walls to divert the flow where it can do least harm. Orchards and gardens are often protected in this way but, where cold air is dammed up above the area that needs shelter, it may still overflow the barrier on

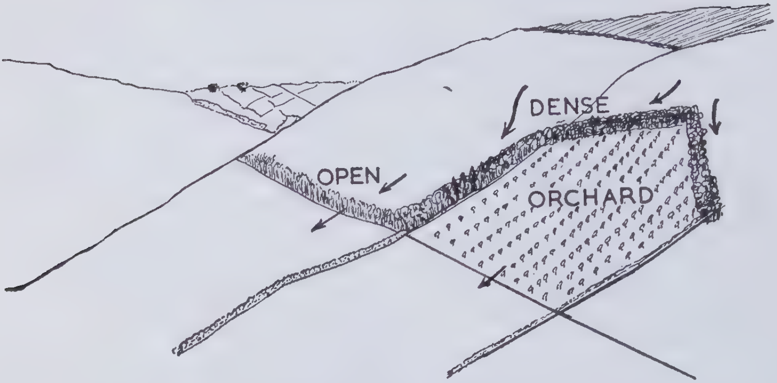
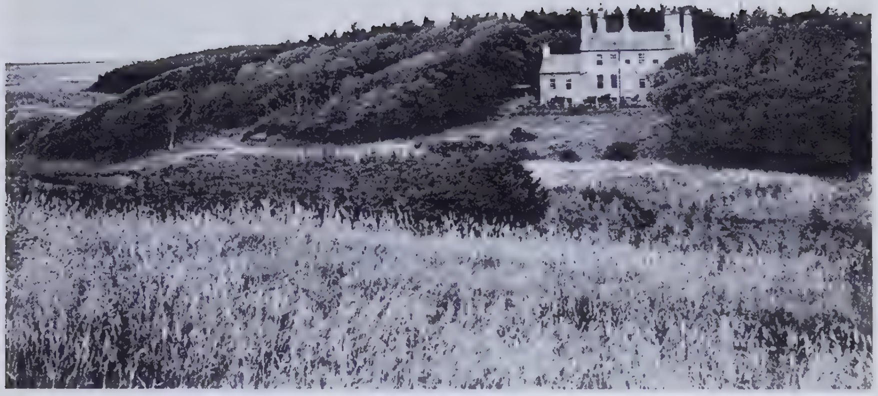


Fig. 9 *Dense belts can be used to divert cold air from orchards. Open belts are necessary on lower slopes to allow maximum drainage.*

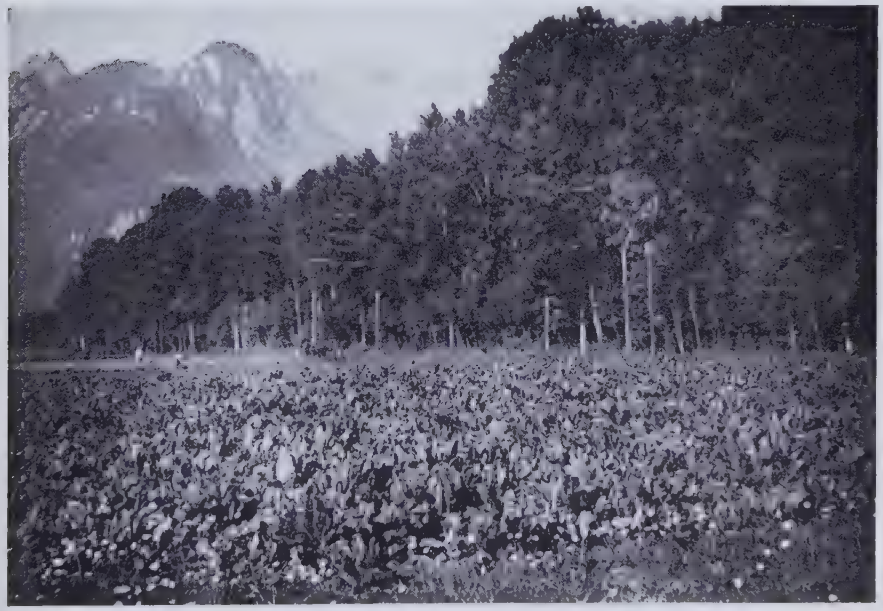
the coldest nights. It is better to guide the stream of cold away, if at all possible, by running barriers across the contour. If it enters the garden, the lower boundary needs to be open, at least at ground level, to let the air creep further down the slope. Measures like these will not prevent the worst frosts of winter but they can reduce their severity where the facilities are available.

Radiation frosts are understood and anticipated; various precautions are practised wherever the risk warrants the expense. Damage is not, however, always apparent immediately: early-sown vegetables may fail to germinate after a spring frost has chilled the ground, or root crops may bolt later on in the season, so that part of the risk is a concealed one.

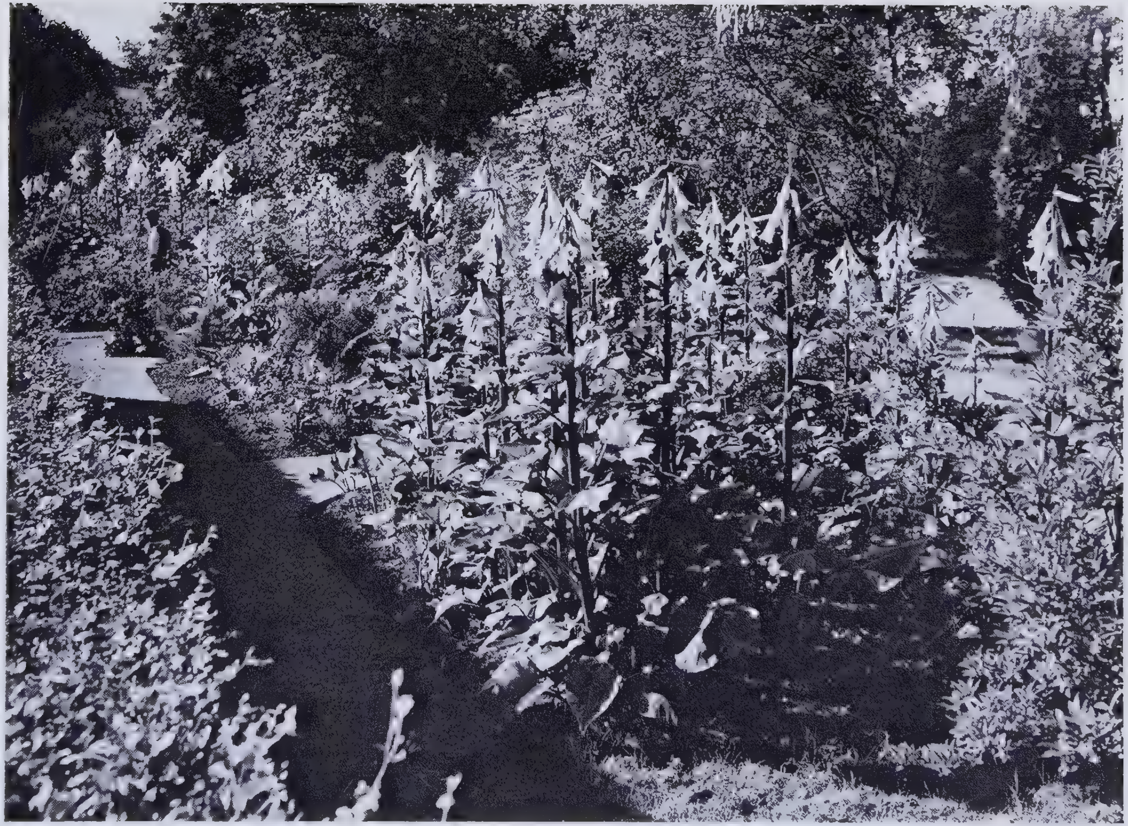
The bitter wind frosts which can be ruinous to the cut-flower industry are a separate problem. Protection against these winds, which may strike only occasionally, may be even more important than shelter against the prevailing directions. It is the milder districts of the country, less attuned to low temperatures, that suffer most; in the flower-growing areas, for example, the mild winters make the profit, which a disastrous wind frost from the Continent can turn into a loss. Some form of mitigating the force of these winds and the damage they cause is the only



1 *Wind-shaped plantations sheltering a house in an exposed district of Caithness*



2 *Shelterbelt of ash, oak, poplar, Weymouth pine and spruce protecting horticultural crops against valley winds, Champ-Bonnet, Switzerland*



3 *Giant lilies in a sheltered corner at Whitchester House, Berwickshire. Beyond the trees in the background,* Rhododendron ponticum *is constantly wind-blasted*

answer. The innumerable hedges of *Veronica*, *Escallonia*, *Pittosporum* and tamarisk encountered in the south-west and in the Channel and Scilly Islands are certain proof of their necessity, otherwise land values would have brought about their removal. What their shelter means in terms of quantity of unblemished, long-stemmed flowers that can be marketed is normally anyone's guess but the Rosewarne experiment in 1953–5, which resulted in an increase of 34 per cent in anemone production behind a lath fence as compared with open ground, is an indication. Windbreaks which are noticeably effective, perhaps only once in five years or so, may still justify their retention, since torn and mutilated flowers, unlike wind-blown farm crops which can somehow be salvaged in part, are a total loss to the grower.

In orchards, too, winds damage the blossom, restrict the activity of pollinating insects and the setting of fruit and, if strong enough, bruise and lacerate the leaves so that their photosynthetic efficiency drops. Besides the physical injury, there is the constant drain on all types of crop through increased transpiration. It is said that multiplying wind speed by four roughly doubles evaporation losses but the quantitative relationship between wind and water loss from plants is not as straightforward. Some maintain that strong winds have no greater effect on transpiration than a gentle breeze. Yet there are other factors to complicate the picture: the bending action of the wind; the leaf's ability to change its position with respect to the wind direction; the water content of the soil, especially its level relative to field capacity and wilting point. Soils may be physically dry, like light sands, or physiologically dry due to waterlogging or acid conditions and the non-availability of water to the plant. There is also a closer dependence on atmospheric temperature and radiant heat, which supplies the energy for transpiration and evaporation, than upon wind speed.

Shelterbelts, particularly those running from east to west, reflect and accumulate considerable heat on the side exposed to the sun. In sunny climates, this strong insolation raises transpiration rates and may cancel out the saving in moisture achieved through lowering the wind. In spite of this, the demand imposed on individual plants is more steady and not accompanied by fluctuations in leaf temperature and, consequently, in vapour pressure inside the leaf, which happens when a turbulent wind has full play. On the other hand, a steady breeze in hot weather has a beneficial influence, minimizing the chance of wilting and scorching. In a simple greenhouse experiment, pots of wheat exposed to a smooth air stream of 4 m.p.h. lost more water than those which were not, but the situation was reversed when the radiation from overhead lamps was intensified. Scorching of leaf tips occurred only with the wheat that was not exposed to the wind. When the wind increased to 7 or 8 m.p.h., differences were smoothed out, the stronger ventilation counteracting the effects of increased radiation.

In similar vein, no differences in transpiration and evaporation have been observed on the two sides of Japanese shelterbelts, where the leeward side was in full sun and the windward side was shaded. Such situations rarely arise in Britain; this balance between insolation and windiness raises serious issues only in climates where further concentration of the sun's heat causes wilting because soil moisture is in limited supply. In such areas, any improvement in water availability produces a positive response in crop yields. They are, in other words, the places where irrigation will always pay, if the water can be found cheaply enough.

Gardeners know well that shelter which lowers the wind and holds the heat forces varieties of fruit that need the extra warmth in our climate. Elizabethan gardeners made good use of the micro-climate of south-facing walls for ripening grapes, apricots and peaches. Quite a number do so today, but north of the Wash, only in favoured spots. Walls facing the sun intercept and absorb the heat and dark-red brick walls, for example, have a different thermal performance from walls of light Cotswold stone. Because the shelter starts on the windward side, they miss the full effect of the south-westerly winds which are the most frequent: it is the other sides which catch the eddies.

Windbreaks for forcing are intensively used in the famous strawberry district of Carpentras in Provence, where the mistral may blow at 30 m.p.h. on as many as 164 days in the year. Both to prevent plants from being torn out of the ground and to ameliorate the chilling cold of the mistral, shelter is imperative. Irrigated plots have cypress windbreaks on all but the south sides, supplemented by close screens of bamboo canes threaded with wire. Set in lines from north to south, main screens are 8 m. apart; shorter screens are at 2 m. intervals, tilted to trap the sun. Under the angle of the smaller screens, strawberries can be ten days earlier than elsewhere; this ingenious method gives a long season from one variety of strawberry.

Time of readiness for horticultural markets is often of greater practical significance than increases in total output and the use of shelter to accelerate maturity has obvious advantages. In Zeeland, returns from strawberries rose by 30 to 35 per cent because windbreaks allowed an earlier harvest. But the overall yield counts also. Intensive cultivation and high production, which become possible, more than cover the capital expenditure on permanent windbreaks and on the labour involved in shifting the portable kinds in many Continental market-gardens. Although often there is less evidence of prolonged wind, such as can be seen within a few miles of any similar venture in this country, with wind-pruned trees for instance, the need for shelter is there. With it, greenhouse conditions can be simulated outdoors for crops that repay the extra warmth and moisture. Windbreaks make the most of the warm summer and concentrate the humidity by preventing wind dissipation of evaporated and transpired moisture.

The effectiveness of shelter in promoting yields varies with the season. Observations need to extend over several years to gauge the average effect. Odd results are interesting but not conclusive, although sometimes useful for comparing different types of screening. In comparison with an unprotected plot, lath shelters, 3 ft high and 24 ft long with a penetrability of 48 per cent, increased potato yields at Rosewarne in 1953 by 21 per cent; solid barriers of straw bales gave a somewhat smaller benefit, whilst a double run of half-inch netting was the least effective of the three but useful for anemones. Crops respond differently to shelter and whereas lath shelters raised the yields of lettuce in 1953 and French beans in 1955 at Luddington, near Stratford-on-Avon, by 43 and 23 per cent respectively, spring cauliflowers showed a negative response in 1954. Even greater increases were measured with French beans at Efford, near Lymington, in 1955, the gross yield being considerably greater near lath screens and the peak of production more than three weeks earlier.

The standard American type of snow fencing, similar to these lath screens, has been successful in boosting vegetable yields in South Dakota. Two parallel lengths of 50 ft, 4 ft high and 60 ft apart, produced no differences in maximum temperatures between the protected strip and outside on 16 days, but on 3 days the sheltered temperature was 1° higher and there were 22 days on which the strip had a temperature 1 to 4° above that in the open field. Detailed studies of plots screened by similar fences, 2.5 m. high, carried out in Jutland, have shown the two outstanding improvements in growing conditions due to shelter to be this temperature increase and reduced water consumption by the plants. Therefore, shelter, from the aspect of improving the climatic environment, would be most beneficial in cold or dry seasons.

Windbreaks have also brought encouraging benefits in orchards. Early experiments at East Malling indicated an increased blossom set where pear trees were sheltered by coir netting and more recent work in Holland showed good results with windbreaks spaced ten times their height apart. Here, it was calculated that windbreaks at intervals of 6 'heights' for apples and 4 'heights' for pears would have yielded a net benefit in 1956 of 73 per cent for apples on vigorous root-stocks and 120 per cent for 'Conference' pears, which are particularly liable to damage from high winds. The corresponding increase for dwarfing apples was 11 per cent. In the preceding season, 'Cox's Orange Pippin' showed the greatest response to shelter, 'James Grieve' and 'Jonathan' registering much smaller increases and 'Golden Delicious' the least. Yet, whilst the protection is valued for young trees, there are growers in Germany and Holland who contend that windbreaks should be removed after the fruit trees reach ten years of age, otherwise they impede the drying of crowns and favour disease. Growing trees to timber height in orchard windbreaks is accordingly not always to be recommended.

These reports hardly stand comparison with those from a survey of 40 citrus groves in California, 20 protected by windbreaks averaging returns of 445 dollars per acre and 20 unprotected yielding only 271 dollars to the acre. On this basis a grower could use one acre out of ten for planting windbreaks and still obtain a considerably higher return from the remaining nine. Hot, dry winds cause orange fruits to fall before they are mature, which is a similar problem in South Africa, besides causing desiccation. But a particularly important aspect of the shelter value is the improved quality of the fruit that it produces. Humidity is the secret, and citrus fruits grown in an atmosphere of high moisture content are smoother, thinner skinned, better coloured, richer and juicier; within limits, shelter can raise the humidity, certainly well above that of the Californian and Arizona deserts. Hence, the marked profits from the windbreaks.

In commercial horticulture, a deterrent to planting live windbreaks is the possibility of harbouring weeds and pests. Hedges and shelterbelts on Dutch bulb fields are believed to have encouraged the bulb fly. Permanent screens are cheaper in the long run but they cannot be moved to fit changes in the demand for shelter. Portable windbreaks have this advantage; they can also be erected after the ground is worked or removed before harvest, provided that erection and dismantling costs are reasonable. Perhaps the main argument in their favour is that they give shelter immediately with little loss of space. Planted barriers involve a wait for the benefits of protection; they occupy more ground and are themselves unproductive, with the exception of the Himalayan Giant blackberry windbreaks used by some East Anglian bulb growers. Strung on wires between wood or concrete posts, these pay for their cost and the strips they occupy.

Strip cropping, whereby tall crops shelter the short ones, overcomes the disadvantages of unproductive tree and shrub belts. Used by itself or as a supplement to planted shelter, strip cropping can be very rewarding if there is an outlet for the crop which forms the windbreak. Winter rye, sunflower, fodder cabbage and maize in strips 0.6 to 1.8 m. wide and 5 to 7 m. apart have successfully raised yields of tomatoes, potatoes and cucumbers in Russia. Strips of rye and maize have boosted sugar beet yields in parts of Germany. Rye, especially, is valued for shelter: it protects newly-planted vines in Hungary, onions in Michigan and carrots on unstable, coastal sands in East Lothian. Bananas do the same for pineapple and coffee in French Guinea.

Low windbreaks are better for sheltering small plots than tall tree-screens. Too much shelter may mean too little sunshine and there is little point in exchanging windiness for unwanted shade and spreading roots that rob the rest of the garden of moisture and minerals. Gardens for pleasure usually make good use of even the most shaded spots, but the commercial grower must watch his space more closely and obtain the best level of shelter his production can afford. It is always a question of finding the worst wind, breaking it and building up from that, bearing in mind that surrounding a plot with shelterbelts, without due thought beforehand, will eventually cut down the sunshine as well as the wind. In the case of a house, it can also block out the view. The smaller the space, the more important these points are. A garden, planned so that tall and low plants, tender and hardy, are interwoven to afford mutual protection, can have as much shelter near the ground and derive as much benefit as one with a tall hedge on the windiest side. The best arrangement depends upon the shelter required: if the house needs protection as much as the garden, taller windbreaks are unavoidable. Tree belts are also best for large areas that regularly require shelter; intensively used market gardens, divided into smaller plots, may be better served by hedges or low windbreaks, whilst areas that move round with a succession of crops, some requiring shelter more than others, are ideally suited to a system of portable screens. It is a matter of securing shelter at the right time and place with the minimum cost and inconvenience.

3 Shelter for Parks, Roads and Rural Estates

PUBLIC PARKS AND RECREATION GROUNDS

Many public parks and gardens fail to make full use of the limited sunshine which the British climate allows. More often than not, sunny days are accompanied by winds that restrict their benefits, especially in spring and early summer when the surrounding seas are still cool and onshore winds have no chance of being warmed. How warm in the sun but how cold in the wind is a familiar expression, which sums up the situation. Pleasant though a breeze may be on the few stifling days of summer, for the greater part of the year it is undesirable.

Few places in the British Isles, away from the south coast, are favoured with more than 1,500 hours of sunshine in the year. Some inland areas, because of upland cloud or industrial smoke, have less than 1,200 and most of the country has to be content with between 1,200 and 1,400 hours. Roughly one-seventh of this total comes in the four winter months, November to February. Rather more can be expected in the two months of March and April, notorious for their cold, blustery winds: so that about one-third of the sunshine comes in cold weather. To this can be added almost another seventh for May, which is still respected for its cool, easterly and northerly winds that often extend into June, the sunniest month in the calendar but not the warmest.

Summer winds are normally less frequent and, in any case, warmer, though sometimes unpleasant. From September onwards they become stronger but still mild until autumn sets in. Taking the period from November to early June, which yields about half of the total sunshine, winds have a chilling effect on even the brightest days and make one less inclined to take advantage of the outdoor sunshine.

Medium-sized gardens that offer a sheltered, sunny spot whatever the mood of the wind are a boon to their fortunate owners. But millions have to rely for outdoor leisure on the green open spaces of cities that are usually too open. Wind cools the body and causes more heat to be lost than on a calm day at the same temperature. A 5 m.p.h. wind at 32° F brings the effective 'calm' temperature down to about 28°. This is why it feels much warmer in shelter than the small air temperature difference would seem to suggest, and why a still cold at 35° below zero in Siberia or North America is much less to be feared than a 0° temperature accompanied by wind. Comfort is not so much a question of gaining more warmth as of adjusting the human body to the rate of heat loss.

Sensation of warmth bears no straight relationship to the external temperature or, for that matter, to wind and temperature combined. The dryness of the air is another factor, which explains why a very dry cold or very dry heat may be quite bearable, while at the same or even lower temperatures a damp, raw cold or sultry, sticky heat is distinctly unpleasant because of the higher humidity involved. On winter days when the warm, dry chinook from the Rockies floods the western Canadian prairie, raising temperatures from well below zero to perhaps 40° F., the weather can be as balmy as an English spring day twenty degrees warmer. Yet a temperature of 40°, with high humidity and a steady wind, can also be disagreeable.

Shelter is needed in public parks not for crops but for flowers, not for stock but for human beings in the open through spring and summer and to a lesser extent in winter also. Breezy sports fields too can often profit from some wind protection to make conditions more attractive for spectators. On some playing grounds a decided advantage may go with the toss, because of a particular wind direction, or line-outs in a rugby game may be concentrated on one side of the field, which is poor for coaching purposes. A few schools have planted windbreaks to overcome these difficulties; more could follow suit.

Planting of trees and shrubs is not overlooked by park superintendents, sports committees and golf Club secretaries. On the contrary, many recreational spaces are strewn with trees and ornamental shrubs, but amenity has usually been the only object behind the planting. Formal arrangements of trees often do little to break the wind where it can be felt: avenue planting is a case in point. Neatly crowned specimen trees, set wide apart, and thin lines of flowering cherries, pleasing though they may be, offer little wind protection and more commonly create greater draughtiness. Winds accelerate between the bare stems

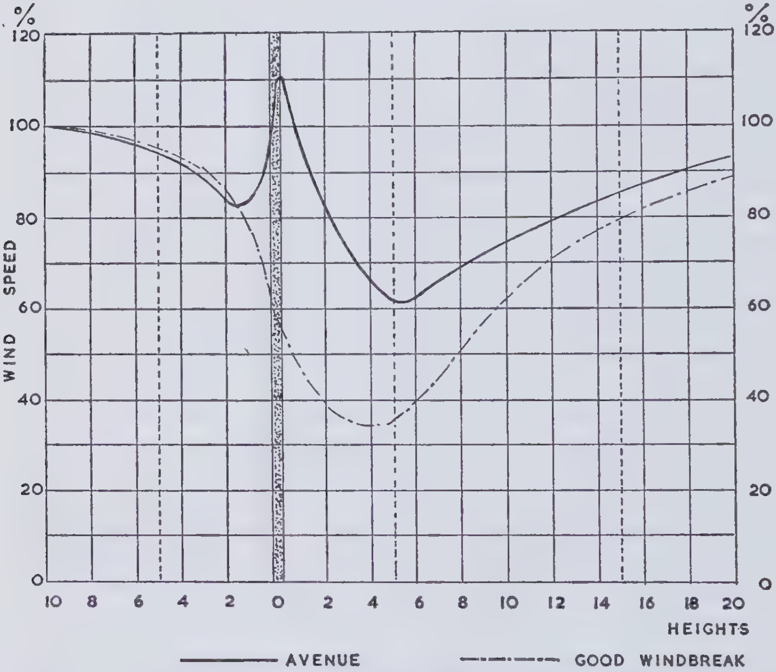


Fig. 10 *Wind accelerates under open avenue belts, reducing their value for shelter (after Nägeli).*

of avenue trees, reaching speeds much higher than way out in the open. Along a roadside in Switzerland, a poplar avenue 14 yards across and 74 feet high, with the trees in each row 7 yards apart and bare of branches for the first 25 feet, caused the wind to reach 111 per cent of its velocity in the open, falling to 80 per cent only after 60 yards or so. The wind in this draughty zone beneath a 50-foot-high chestnut avenue in Germany rose to 120 per cent of its normal value; it remained above 100 per cent until nearly 50 yards down-wind. Far from reducing the wind, avenues open in the trunk space increase it, as the air stream escapes beneath the crowns.

This jetting of the wind damages flowers and crops on the leeward side and is uncomfortable for animals and human beings. Limes, if well arranged initially, and certain conifers may be satisfactory, provided that they form a continuous curtain of foliage and branches right down to the ground, but they are not the common type of avenue encountered in parks. Grouping or massing of trees and shrubs in clumps or informal strips instead of regimented lines, as seen in some Scandinavian cities, produces a better decorative effect and more shelter. Breaking up large stretches that are open to the sweep of the wind can combine a more congenial local climate with greater character and interest. It also helps to baffle the noise of traffic.

City park authorities are not concerned with timber production, only with ornamental values. The aim of producing shapely trees with well-balanced crowns has therefore led to the practice of planting trees singly. Low upkeep cost is important and it may be suggested that single trees require less expert attention than clumps or groups of mixed species with varying growth characteristics. This is doubtful; pruning is always expensive and, furthermore, the free-standing tree is always more vulnerable to various forms of damage than one in a composite group.

Planting for shelter in parks and open spaces raises no problems of root robbery or of pests that might attack economic crops, so that the choice of species is fairly wide. Windbreaks need have no utilitarian appearance, and ornamental species with coloured foliage or flowering trees and shrubs, which are desirable in town planting, can easily be incorporated. Tolerance of smoke or other forms of atmospheric pollution imposes certain restrictions on species, but the choice is still much wider than in the case of a hill farm shelterbelt.

ROADS AND RAILWAYS

There are pockets along many highways, particularly when emerging from cuttings, where furious gusts can catch a car broadside and have a disconcerting effect on the driver, even a dangerous one at high speeds. Vehicles caught in sudden down-draughts are occasionally thrown off mountain roads like Rest-and-be-Thankful in Argyllshire. Not all these hazardous spots could be improved by shelterbelts, particularly in the wild, broken country of the Highlands, but some could.

On a rather different plane, the planting of trees and shrubs between dual carriage-ways for amenity, and to reduce the dazzle from oncoming headlights, is not a question of shelter. But shelter becomes involved if such planting increases the danger of snow drifting. What is usually preferred is a quick-growing but compact shrub, oblivious to exhaust fumes and requiring little maintenance, the type of barrier which can block a road with snow if there is no means of trapping it elsewhere. Snow-collecting fences are being adopted more and more to keep roads open; Kent has put them to good use for many years and the practice is spreading. The Road Research Laboratory has also devoted considerable attention to their siting and structure and to the mechanics of snow drifting in their vicinity. Infrequent, though often sudden and paralysing, snow storms impose a need for some sort of control, and portable snow fences are the obvious answer. These are expensive and costly to erect and dismantle but there is rarely any difficulty in getting them set up on privately-owned land bordering roads. Land on which to plant permanent snow-breaks would be a different matter and would be unthinkable where land values are high. However, there are places where planting would be the best solution.

Solid fences produce drifts on both sides, while more open structures keep the drifts to the leeward side. Leeward drifts near solid barriers are usually short and deep, reaching saturation point fairly quickly; those near penetrable fences are long and shallow and absorb more snow. These drifts creep nearer the fence the higher the wind. Solid fences are useful where limited space is available for snow collection but types with a density of roughly 50 per cent, e.g. 1½-inch vertical laths at 3-inch centres, are better and if these are raised six inches or so from the ground snow collection is even more efficient. The maximum drift length can be calculated for fences of known density. Thus, for a 50 per cent barrier 4 ft high, drifts extend for $36 + 5 \times 4 = 56$ ft; for a similar 3-ft fence the length is $36 + 5 \times 3 = 51$ ft. More penetrable fences extend the drifting; the figures above would need to be divided by a factor less than unity, e.g. 0.8 for a 35 per cent barrier. Denser structures shorten the maximum length of drift; using a factor of 1.28 for a 70 per cent barrier, the length becomes 44 ft for a 4-ft fence and 40 ft for the 3-ft model. On top of these calculated lengths, a safety allowance of 16 ft is recommended.

Most tree windbreaks, because of their greater height, create longer drifts if there is enough snow; on the other hand, they can hold more. In Germany, the Monschau type of hedge, close at the bottom but with a fair number of saplings allowed to protrude above the general level to heights of, generally, 15 to 18 ft, piles up the snow from about 49 ft on the windward side to 50 to 66 ft behind the hedge. The bulk of the snow lodges along a leeward strip 33 to 40 ft wide. Shelterbelts with an underwood contain the drifts within 100 ft of the leeward edge at the outside; those that are more open behave differently. In Manitoba, belts established for highway protection are located, on average, 150 ft from road boundaries. In Saskatchewan, no farm shelterbelt is normally allowed closer than 300 ft. A great many snow fences in this country, of the conventional type, are situated about 100 ft from road verges and work satisfactorily but there have been cases in Germany where 5-ft fences have been too near to the road at 80 ft.

Materials used for snow fences along roads and railways range from sleeper palisades, chestnut paling, lath fencing and hoardings to the coir netting favoured on the Continent, and shelterbelts. Snow accumulation near different types of strip plantings has been carefully observed in Russia and North America, where winter snow contributes considerably to total precipitation. Windbreaks are then planned to spread the snow as uniformly as possible over the fields without letting it drift into gullies and ravines. Lodging close to the trees is discouraged through keeping windbreaks slightly more open near the ground. Belts with an outer row of shrubs trap most of the snow within 10 to 25 yards of the leeward edge but narrow belts of pruned trees allow the snow to sweep underneath and settle in a thin sheet over, perhaps, 300 yards. Consequently, narrow belts that can be kept thin at the bottom are preferred.

The drifting pattern near a shelterbelt or other barrier fundamentally reflects the local wind conditions and the extent to which the shelter affects them. But straightforward forecasting of the length and type of drift which can be expected near a shelterbelt or even a snow fence is complicated by other factors. For the final drift pattern depends also upon the amount of snow transported by the wind, which means that a wind approaching over a high stubble deposits more snow than it can pick up and forms a different drift at the end from the same wind that has passed over a smooth, fallow field. Again, much depends on whether there is any low vegetation near a barrier to initiate drifting.

Alongside a mile-long shelterbelt in Canada in the 1956–7 winter, the roadway on the windward side remained clear of snow for the first half-mile but was impassable for the second, the drifts formed in the lee of the belt being, respectively, shallow and extending for 10 to 12 yards and deep, extending to only 5 or 6 yards. This was due to the fact that the wind approached the first section over stubble and then lost more snow amongst weeds on either side of the road, whilst, for the second half-mile, fallow extended right up to the road. Yet there was no change in the structure of the shelterbelt, so that the height and permeability are not the only two variables which decide the form of drift near an obstacle.

However, an important feature of windbreaks destined to trap snow is a light shrub row to sieve the snow and start drifting. Alternatively, densely planted shelterbelts may cause a lot of snow to be blown over the trees and deposited in a short drift. A zigzag line of belt, about 100 yards from the road, is effective in the German Westerwald because the wind is concentrated in the 'wedges', its force taking all the snow over the tops. But a belt that is moderately dense will usually do all that is required and it is better to have a structure that is on the

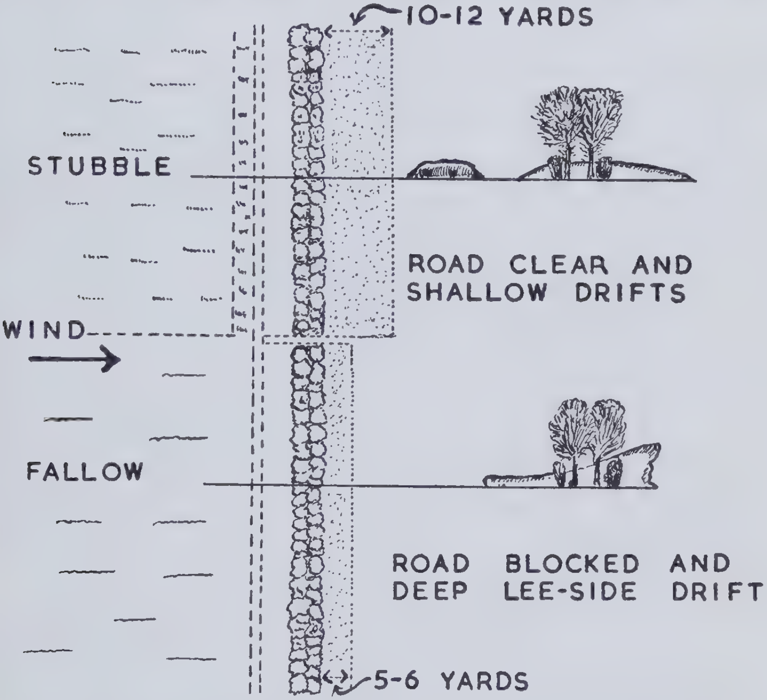

10-12 YARDS
STUBBLE
ROAD CLEAR AND SHALLOW DRIFTS
WIND
FALLOW
ROAD BLOCKED AND DEEP LEE-SIDE DRIFT
5-6 YARDS

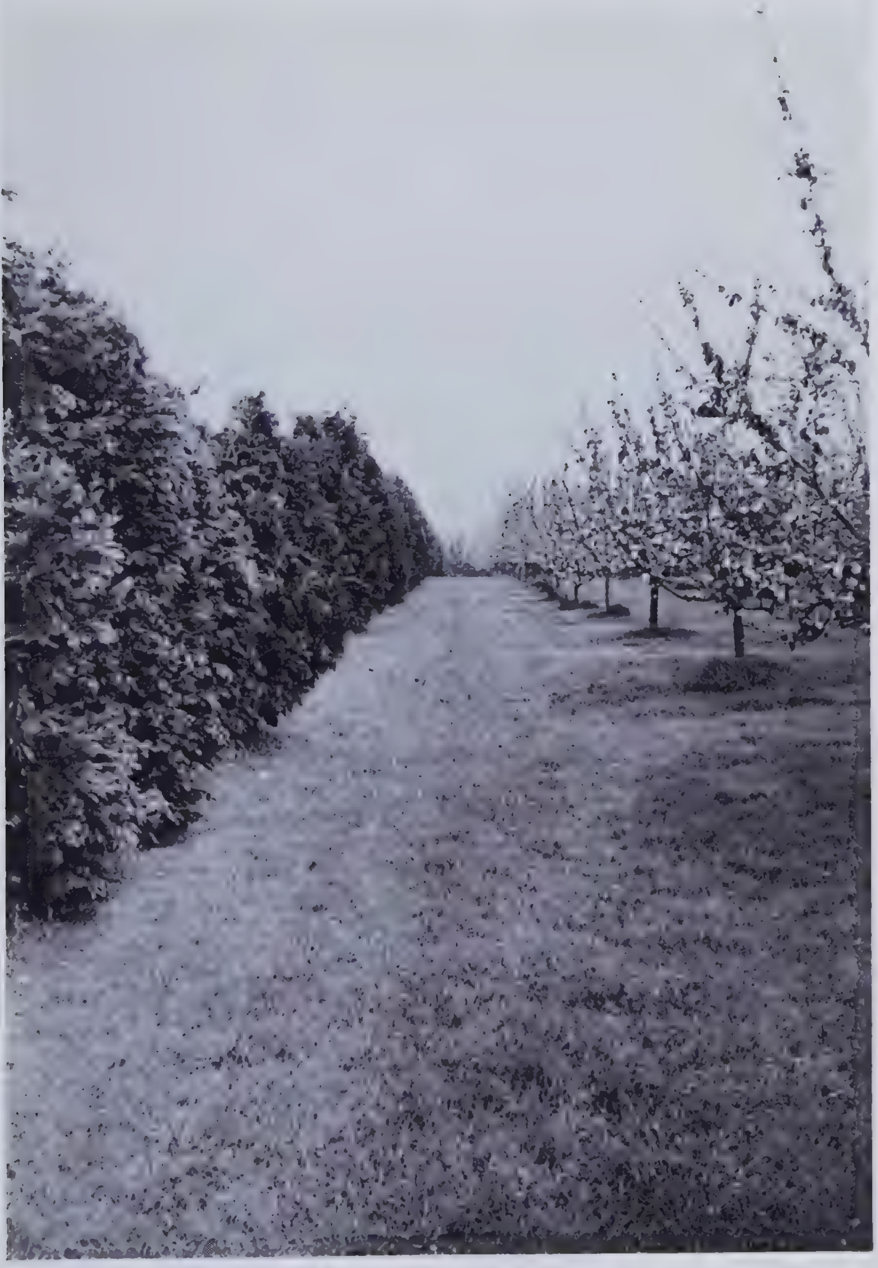
Fig. 11 *Snow drift patterns observed beside a Canadian shelterbelt, showing the influence of the up-wind terrain on drift formation.*

dense side than one which is too open, especially near ground level, if the aim is to collect rather than distribute the snow. More snow will also accumulate on the windward side of a belt or beneath the trees if a wider spacing of trees on this side is adopted. With young pines, however, snow drifts damage the trees so that it is better to let as much snow as possible pass through to the leeward side before lodging in deep drifts. Another point to watch is that planted snow fences do not thin out near the ground and block the road or railway they are intended to protect.

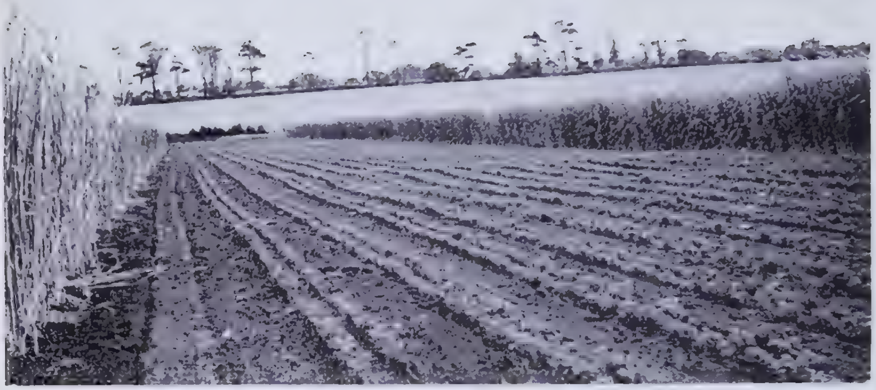
Provided the topography is reasonably uncomplicated, it is not difficult to plan windbreaks to serve a useful purpose against winter snow storms. Hilly districts present more problems and wind currents change remarkably with slight changes in wind direction. Plantations, unlike snow fences, cannot be readily moved if their first position proves unsuitable and it is imperative to know the directions from which the snow comes to the spot in question; local obstacles may modify the general direction very appreciably. Bearing this in mind, shelterbelts can help to alleviate the problem of snow on roads and railways in places where low fences are insufficient for the purpose. The Norwegian State Railways have established plantations to check the snow at elevations up to 2,500 ft., where fences would have been of little value.

ESTATES

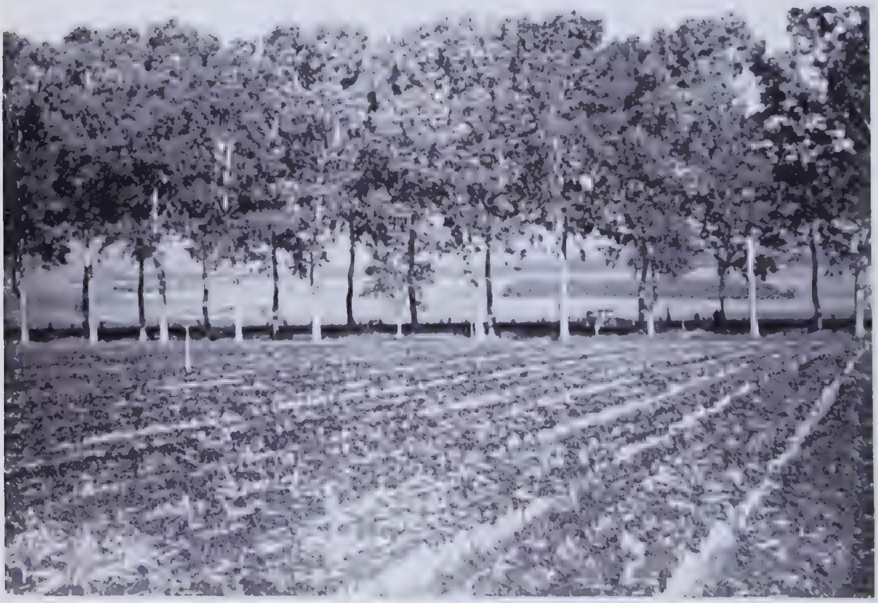
Aesthetic motives, sporting interests and purposes of utility, in that order, have given the impetus to estate planting in the past, although the order might well be reversed today. Parks were fashionable from Norman and Plantagenet times but the arboricultural movement acquired major importance only in the late seventeenth century. Introductions such as the maple, Norway spruce, European larch and silver fir aroused interest; past success with other introductions, notably sycamore and horse chestnut, inspired confidence. The Tudors had framed their mansions with gardens; now it was the turn of 'natural'



4 *Single-row windbreak of Lawson and Leyland cypress at 9 years. Trees at 4 ft spacing*



5 *Strip-cropping using rye to shelter carrots and control soil-blowing on reclaimed sands in East Lothian*



6 *An avenue of poplars in Switzerland. High wind speeds are produced in the open space between the stems*

landscape gardening, which, championed by 'Capability' Brown, reached its peak about 1780, to extend these activities to policies and open estate land. Clumps of ornamental trees, groves and strips began to break up the surroundings of the great houses.

The competitive element was strong, overshadowing any motive of profit; prosperity promised by contemporary developments in farming encouraged landowners to vie with each other for possession of the most elaborate plantings. The bulk of estate plantations was established between 1760 and 1820 and towards the end a more utilitarian approach gathered weight. Interest was maintained rather longer in Scotland, stimulated by a spate of new introductions, especially many of the North American conifers. Wales, with fewer wealthy estates, was least affected by the arboricultural tide and until well into the nineteenth century planting stock had to make the long and hazardous journey from Scotland, a large proportion being doomed to failure.

The virtually treeless countryside of south Scotland in particular was transformed during this period. The 'cold, naked country' of Tweed-dale, as it was described in 1746, became clothed in woodlands. New estates blossomed in unlikely places, like Gosford on the barren shores of the Firth of Forth and Whim on the bleak flow-moss at Leadburn, in Peebles-shire. There was a growing appreciation of the fact that sheltering woodlands could combat the harsh conditions on hitherto open farmland. Many of today's good farms were carved out of wet, windswept moor and cold, unpromising upland at this time, often with shelter as a firm foundation on which to build improvements. The Cockburn estate in Midlothian, on the northern slopes of the Pentlands, is perhaps one of the finest examples of an intensive scheme of planting for shelter from this period. A grid arrangement of shelterbelts was planted about 1820, embracing three or four farms, whose fields were sheltered on all sides; the long-term value of this particular project can be readily appreciated on the present farm of Cockdurno.

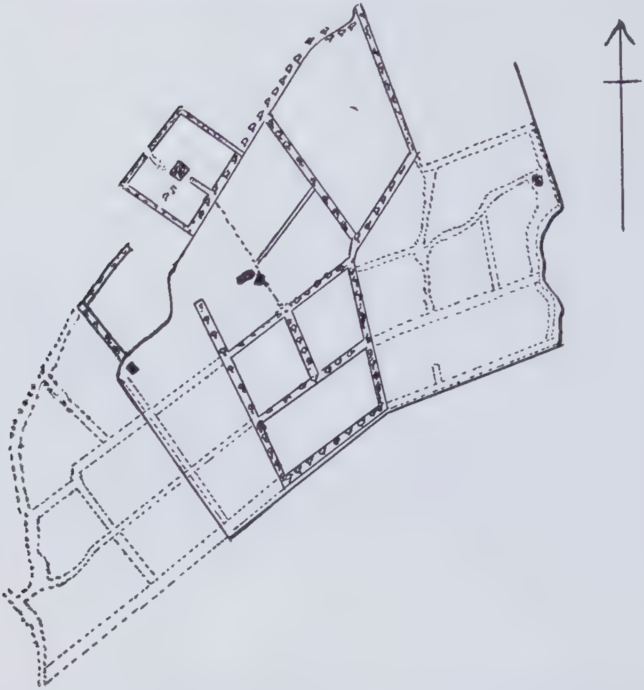


Fig. 12 *An early nineteenth-century system of shelterbelts, Midlothian. Central part preserved.*

Plantations in many places ameliorated the rigours of northern climates. Their influences were soon apparent and recorded by contemporary chroniclers. The southern, central and north-eastern counties of Scotland, some Northumbrian valleys and, indeed, most districts where major changes in land use were being engineered or farms and estates consolidated, abound in examples. The enclosure of commons was proceeding and often plantations were incorporated for shelter, as in the Lomonds of Falkland in Fife. Parts of the windy East Anglian breckland were enclosed with pine hedgerows of Scottish provenance, and over in Shropshire the lands of Wildmoors were divided and interspersed with plantations to shut off the cold blasts coming round the Wrekin from the Welsh mountains. Fortunately, the planting spirit coincided with the spread of enclosures and new farming methods to previously undeveloped districts. As new farms were being laid out or existing ones rearranged, it was convenient to include more plantations. Localities with long-established patterns of land divisions and well-grown hedgerows, as well as more old woodland, had less to gain from further planting.

Planting for shelter was urged on landowners by the Scottish Parliament as early as 1457, probably to little avail, and was the basis of improvement of the 10,000-acre Monymusk estate early in the eighteenth century. But it was the first half of the following century which gave publicity to sheltering strips of woodland, or 'screen plantations' as they were called until the arrival of the American terms 'shelterbelt' and 'windbreak' some decades later.

In terms of meteorological factors, changes produced near shelter plantations appear small but in terms of farm management and income on otherwise exposed areas they attain greater significance. The benefits that ensue from planting are slow to mature but cumulative, a point well demonstrated by farms which have enjoyed wind protection for more than a hundred years.

International and economic developments at the close of the nineteenth century halted planting for the improvement of agriculture. Some commercial planting continued, but on a reduced scale. There were still estates that could maintain the triple interests of timber, game and shelter but the decline in agriculture stripped many shelterbelts and other woodland of useful timber or left them neglected. Shelter as an aid to farming was largely disregarded for at least a couple of generations.

With the re-awakened interest in recent years has come a more critical approach to shelter. Droughts are fairly infrequent or of short duration; wind erosion is a localized problem, if serious where it occurs. Also, the common landscape pattern of small enclosures, hedgerows and woodland which prevails over much of the better agricultural land has combined with the varied relief to give an appreciable degree of shelter. Yet a large part of the country is exposed to winds that are detrimental to farming throughout the year or at critical seasons, even though their ill-effects may not be conspicuous. Besides vast hill and upland areas, surely capable of further development, there are lowland districts, potentially highly productive, but running below this level because of windiness. In order to sustain the annual loss of farmland to urbanization and industry, mostly good ground on town perimeters, higher production from the land that remains available to the farmer appears imperative. The intelligent provision of more windbreaks could be a step in this direction.

From the farmer's point of view, there are definite benefits to be derived from shelter, both in cropping and stock farming. Naturally, these benefits must cover the cost of the shelterbelts and compensate for the land occupied. The evidence available suggests that they will wherever the wind is something to be taken into account in the normal run of farm work.

The sacrifice of land is often a deterrent to planting shelterbelts. But over a large part of the countryside, old hedges occupy more space than would be needed for well-planned shelterbelts and generally never repay the cost of trimming. On stock farms they provide useful shelter and shade but the ever-widening gaps, common in hedges that have been allowed too much rein, reduce their efficiency. Mechanized crop farming requires larger fields and fewer hedges but opening up the landscape to meet this need means increasing the wind problem. This is where windbreaks could be incorporated while still providing a better farm layout to suit modern trends. It has been carried out successfully in parts of Germany under the programme for *Flurbereinigung*, the redistribution of land involving the unification of fragmented agricultural holdings, the straightening of field boundaries and the rationalization of land use.

The decision to employ shelterbelts, like the decision to irrigate, must be related to the intensified productivity that can be expected. Estimated future returns must justify the expenditure. But, unlike irrigation, the results of shelter take time to come into effect. It is natural, therefore, for the tenant farmer, if not on a long lease, to approach planting with some reluctance.

The planting of trees is not usually regarded as an improvement for which a tenant can claim compensation upon expiry of his lease. Owner-occupiers and landlords, however, can take a somewhat longer and wider view of shelter planting. Property improvement is a gradual process and so long as land prices continue to rise, permanent improvements that are in step with productivity are a safe investment. If, as has been said, adequate shelter has the effect of removing a farm three degrees of latitude further south, with all the advantages that are implied, well-arranged windbreaks should raise market values or justify higher rents. Planting in this way is a long-term improvement.

A particularly important aspect of shelter as a long-term improvement is to be found in the use of shelterbelts as a basis for a revised type of farming or management. With shelter, exposed arable areas may be adapted for a more remunerative cropping plan; upland districts may become capable of supporting more productive but less hardy breeds of livestock or, perhaps, winter ewe hoggs at home; hill farms may be able to practise earlier lambing and calving. Shelterbelts in such cases form a foundation for an upward trend in farm management and income.

Estates with timber interests, probably including a sawmill or outlets for produce, have the additional advantage of employing shelterbelts, on farms in hand or tenanted, as a supplementary source of material. Although scattered shelterbelts may be more costly to work, their area may serve to bring the total woodland area of an estate up to a more economic figure, spreading overheads, labour and equipment and even making it possible to employ a skilled forester. In addition, estate shelterbelts have a sporting value; many mature shelterbelts owe their composition and hence, quite frequently, their efficiency to the influence of the gamekeeper. Shelterbelts with the ground cover that is necessary for preventing the wind from sweeping under the trees are ideal for game and shelter. Narrower windbreaks, although no use for nesting cover, make excellent game rises. So that timber and sporting values, from the estate's point of view, may add considerably to their shelter value as regards farming.

Finally, the amenity aspect of shelter planting must also be taken into consideration. Shelterbelts can be functional and still ornamental and the range of possible species for planting allows plenty of scope in this direction wherever appearance counts. In comparison with steppe or prairie, Britain is favoured as regards climate, if not always as regards weather. Trees grow, without much difficulty, in most parts, except on some high slopes and mountain summits where exposure is aggravated by thin and wasted soils. Windswept places along coasts and amongst hills may not provide trees of timber value, but sufficient to shelter livestock, vegetation and the soil. Indigenous trees and shrubs, together with the wide range of exotics which have become adapted to the British climate, provide a wealth of planting materials from which it is possible to select stock suitable for most purposes and situations, although the choice shortens as one climbs higher into the wind or on to poor soils.

4 Shelter and Farm Crops

Farmland that is interspersed with forests and plantations frequently appears to have an extra richness. Parts of Europe where forestry and farming are closely interwoven show this very forcibly, but the tree-strewn landscape of some lowland counties and valley plains in Britain arouse the same general impression. In the north or on higher ground, the pasture behind a strip of woodland may seem more fresh and lush than elsewhere or cattle may appear more contented and comfortable grazing in the lee of the trees on a cold, blustery day. The exact value of such shelter is often elusive. One certain way of demonstrating just what benefits a belt of trees confers on adjoining land would be to cut it down and see what happens afterwards. This would be a drastic course to adopt. Shelter benefits develop gradually, growing with the trees, so that there is no sudden, perceptible change after creating new plantations. However, areas that are sheltered can be compared with others that are not and certain crop and animal responses to shelter can be measured experimentally. At other times straightforward deduction can indicate the value of shelter and explain why shelter is useful: for example, a critical examination of the effects of wind and inclement weather on plants or animals can be related to measured changes in local climatic conditions near shelterbelts.

But the weather ahead is always an unknown quantity and no accurate forecast of the benefits shelterbelts will bring in a particular season is therefore possible. Notwithstanding, there is a considerable array of evidence from various countries which is overwhelmingly in favour of shelter against the wind.

A well-known instance of this is that the accumulation of warmth in the lee of hedgerows, walls and plantations gives rise to the 'early bite' that is welcomed by shepherds. In the same way, shelterbelts on upland farms allow the production of field crops which would otherwise find temperature conditions barely sufficient for their needs. About 20 million acres of the land surface of Great Britain lie above 500 ft and nearly 14 million acres are estimated to be in upland and hill farms. As altitude increases so does windiness, while at the same time the mean temperature decreases at the rate of 1° F. for every 270 ft rise. Consequently, there is a progressive shortening of the growing season as one climbs from the lowlands to the hills. It is this factor which puts many upland farms in the marginal category in spite of their soil potential.

In maritime climates the growing season is harder to define than in continental areas far from the sea, where it can be sharply determined by the last killing frost of spring and the first killing frost of autumn. In Europe, 42° F. or 6° C. is the conventional threshold value for measuring the growing season. This is a convenient standard for purposes of comparison, not an indication that all vegetation begins to grow at this temperature and not before. Obviously, the snowdrop and the sunflower differ in their heat requirements. In the same way, 10° C. or 50° F. has been used as a basis for climatic classification of European forest types, on the grounds that at this temperature vegetation is active in all species.

Using this system, the growing season in Scotland falls with altitude to some 112 days at 2,250 ft and to about 100 days at 2,450 ft. By itself, this statement means little; parts of Saskatchewan at this elevation experience a growing season of 90 days, yet manage to produce abundant wheat and ripen tomatoes outdoors. The temperature amplitude or total warmth received is important and for this reason growing season is generally expressed in terms of accumulated temperature, giving the sum of 'day-degrees' above or below the threshold value in a period of time.

With the mild winters of the Atlantic seaboard, many coastal points rarely experience mean monthly temperatures below 42° F. and growth continues slowly all the year round in some species. Other areas reach a monthly mean of 42° F. in March, whilst more elevated situations may not warm up sufficiently until June. Ben Nevis only rarely achieves a temperature of 42° F. in July and August. In comparison with the lowlands, a Cumberland village at 1,500 feet has a growing season about 10 weeks shorter; it is nearly 3 weeks shorter still at 1,900 feet.

Farmers and gardeners are accustomed to such variations between districts in the onset of growth, the beginning of the lambing season and the appearance of blossom. Some years ago a comparison of flowering and fruiting dates for selected plants revealed pronounced differences within comparatively small distances. Altitudinal change does not provide the complete answer, aspect being equally important. It has been said that a farm hanging to the south and more or less protected from the north should be worth at least 20 per cent more than less fortunate farms nearby. South-facing slopes which catch the sun are notoriously early in relation to their northern neighbours, although the difference is less noticeable in dull, overcast weather or when moderate winds play on the southerly aspects. When there is little wind disturbance the air nearest the ground is warmest by day and allows the soil or vegetation to absorb heat more freely. The texture of the soil and its capacity to hold the warmth play a prominent part: sandy soils can be as much as 10 or 12 days earlier than nearby peaty soils. For these reasons, it is difficult to represent the growing season at all accurately on a map.

Nevertheless, a rise in elevation of only a few hundred feet can so restrict the length and intensity of the growing season that the raising of many arable crops is attended with considerable risk. The reluctance of crops to ripen, delaying harvesting into autumn when there is less chance for cereals to dry out, is a serious drawback. It is because the effective growing season, already short, is curtailed still further by the incidence of strong winds that shelter can be valuable. Although upland farms welcome drying winds at harvest time, their adverse effects at other times in the season may more than cancel out this benefit. The latitudinal and altitudinal limits of forest are determined primarily by temperature conditions but wind can preclude the existence of forest long before the threshold temperature is reached. In a similar manner, this combination of low temperature and wind determines the limits of arable farming types in the British Isles.

Shelter against the wind will effectively conserve heat and extend the growing season on exposed hill and upland farms. Shelter can make possible a type of farming or management that would be too risky otherwise. It can allow a standard of farming to be reached that is much more comparable with that on more favoured lowland farms. Concrete evidence to this effect has been bequeathed by bygone planting enthusiasts. The intensive management of the high-lying Cockburn and Cockdurno farms on the northern slopes of the Pentland Hills could hardly have been contemplated without the network of shelterbelts that has been there for 140 years. Without shelter, dairying at that elevation would be a much more hazardous venture. One has only to look at neighbouring land to south and west to appreciate this.

Climatic factors are so closely knit one with another that any effect on wind involves all the other elements indirectly. Corresponding changes are imposed on those factors which affect plant growth, giving the sheltered plant a more favourable environment in which to germinate, grow and mature than when exposed. It is the ultimate effect of these changes on the quantity or quality of crop yields that interests the farmer. Records of total yield increases in field crops and pasture adjacent to shelterbelts or artificial windbreaks have come from places as far apart as Russia and North America, Scandinavia and New Zealand. Inevitably, the variation is enormous; different crops respond differently to shelter, according to their natural wind-hardiness and their overall environment, which has ranged from the continental extreme to the equable oceanic climate of smaller land masses. Furthermore, crop production depends upon the weather during the season in question and to some degree on the weather of the previous summer and winter. What may be a true picture of shelter effect for one period of a few years may be quite different from the average during a subsequent period, due to cyclical changes in weather conditions. These, then, are the limitations of published figures; they can be a guide but not a criterion of the potential value of shelterbelts in any particular region or for any particular crop.

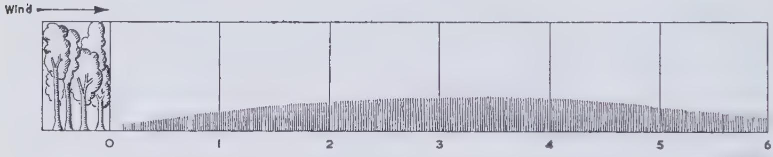
Farmers, however, are not likely to accept such figures without caution. On the contrary, their intimate knowledge of their own locality's characteristics permits them to sift from the published information just what promises to be of some use to them. But the value of these figures lies in the fact that they show that shelter can increase yields, quite apart from reducing wind damage and preventing soil erosion, which are the two main points which usually spring to mind when shelterbelts are mentioned.

In many cases there is a loss in the yield of arable crops within a narrow strip bordering a shelterbelt, on account of shading, drip from the trees and root competition, the last most acute in low rainfall areas. In Canada and on the Great Plains, the loss is accentuated by the custom of fallowing a border round the trees so as to give their roots a wider feeding area, but this is not necessary under our conditions. A falling-off in the crop near the trees is only noticeable in Britain when shading or accumulated wetness delay growth in relation to the rest of the field. Beyond this marginal area, increased yields extend down-wind on average to 10 or 12 times the height of the trees, which is the zone of the major improvement in ground climate. In the classic studies of the American, C. G. Bates, crop measurements made in about 25 fields in Nebraska, Iowa and Minnesota in 1908 and in nearly 50 fields in South Dakota, Nebraska and Kansas in 1935, all fields being protected on one side by a shelterbelt, a maximum increase of yield of about 45 per cent above the field average was found at 4 to 5 tree-heights from the shelterbelts. His results encouraged further planting.

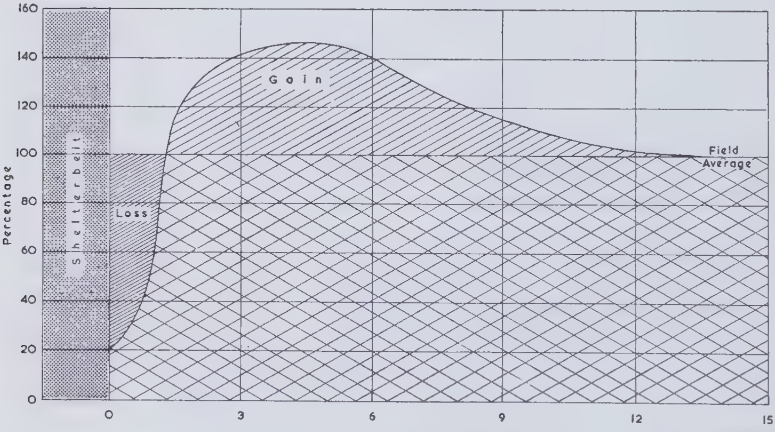
A more recent American survey in the three crop years, 1952 to 1954, showed that 274 out of 331 farmers interviewed claimed increased yields near planted belts and furnished relevant estimates; 18 more noted improvements in yield but could not estimate the amount, whilst only 39 reported no extra yield, 2 claiming an actual decrease. On balance, the average increases per acre for all fields under observation were:

Maize	6.7 bushels	Soya beans	5.5 bushels
Oats	6.5 ,,	Rye	6.0 ,,
Wheat	2.3 ,,	Potatoes	80.0 ,,
Flax	3.0 ,,	Alfalfa	0.56 tons
Barley	7.4 ,,	Maize silage	3.5 ,,

Increases of this order and even greater are reported frequently in Russian journals, the differences being particularly



DIAGRAMMATIC CROSS SECTION THROUGH SHELTERBELT AND CORN CROP



PERCENTAGE LOSS OR GAIN IN CROP GROWTH

Fig. 13 Average effect of a large sample of windbreaks on crop yields, U.S.A. (after Bates).

pronounced in areas where water is a limiting factor. During favourable years cereal yields have been 10 to 12 per cent higher in sheltered fields than in the open steppe; in moderately dry years increases have been 40 to 100 per cent and in droughty seasons have soared between 100 and 400 per cent. The mean excess yield attributable to shelter there has been put at 24 per cent in the case of cereals and potatoes. In Rumania, wheat yields in sheltered fields in 1952 and 1953 were up by 20 per cent in the Dobrudja steppe and by 50 per cent in Baragan, oats in the latter yielding 18 per cent more. These are startling figures, indicating the difficult climate with which farmers have to contend without some means of protecting the crops.

The influence of shelter on crop production in continental areas has been variously attributed to protection from hot, drying winds during critical stages of the growing season, reduction in evaporation rates due to lower surface wind velocities, reduction in crop damage by storms and strong winds during later stages of development, reduction of fallen ears in crops infected with borers, added soil moisture from trapped snow, reduction in injury to young seedlings by blown soil or through uprooting and to the earlier warming-up of sheltered soils. However, even in semi-arid regions of the world, not all the evidence has been so strongly in support of shelterbelts. Investigations carried out over five years in Saskatchewan revealed a net yield increase due to shelter of only 0.7 bushels per acre, taking into account the area occupied by windbreaks or rendered unproductive through the fallow cultivation of belt margins. Admittedly, these yields tapered from 26 to 27 bushels nearest the shelterbelts to about 20 bushels per acre in the centre of the fields. Here, they showed a marked correlation with the extra moisture available from winter snow drifts piled up behind the trees. In such cases, it is difficult to dissociate the effect on crops of wind protection during the growing season and the snow-trapping effect in the winter. Steps have been taken to isolate these two aspects by erecting artificial windbreaks after the spring thaw and after the ground has been uniformly cultivated and seeded but such investigations require several years of observation before reliable data can be obtained.

In the dry-land farming areas of Canada, the U.S.A. and U.S.S.R., crops grow under conditions of less than optimum moisture. Any augmentation of the supply, however small, is likely to produce an immediate response from the crop. It is the combined effect of shelterbelt influences on factors affecting the hydrological balance that has accounted for the extraordinary increases in crop production near shelterbelts in the U.S.A. and U.S.S.R. Important points brought out in the Canadian prairie investigations are that the windbreaks trap snow which would otherwise be blown into gullies and make possible a reasonable crop in exceptionally dry years when those in exposed places have been a total failure. The stubble from previous crops is relied upon to form a mulch during fallow periods, usually every alternate year, to guard the soil against blowing and to conserve moisture for the next crop, so that crop failures jeopardize the crops of subsequent years.

Such figures can hardly apply to wetter climates but it might be borne in mind that there are districts in the British Isles where seasonal shortages of water occur. Irrigation is regaining the interest it held more than a century ago and has paid handsomely in some districts during 1960 and 1961. Clearly, moisture conservation in farming warrants a little more attention even in our climate. Providing shelterbelts would help.

In general, however, it may be anticipated that improved yields of field crops near shelterbelts in this country will find a closer correlation with the temperature regime than with moisture conditions. The checking of evaporation and transpiration behind shelters contributes to this conservation of heat. Top soil temperatures down to 4 inches have been observed to decrease 3° C. in the space of 30 yards behind a tall hedge. Lack of warmth and sunshine are the prominent features of the British summer and are reflected in farm profits. A cold, damp spring, when land gets little opportunity to warm, gets a season off to a bad start and lateness becomes more serious as one travels northwards. Crops vary in their heat requirements to initiate growth but a degree or two difference can mean an earlier start of a few days or even a couple of weeks. An early start with sugar beet, for example, means a longer period at the other end of the cycle for sugar formation. But low temperatures in the early stages of leaf and root development result in a high proportion of 'bolters'.

Shelter for sugar beet has received careful study in Germany, where investigations have shown a weight increase of 10 to 14 per cent as far as 18 'heights' behind windbreaks and 7 to 8 per cent averaged over 30 'heights' leeward. At the same time the sugar content of the roots increased by about 3 per cent, raising the total sugar yield near windbreaks by something like 8 or 10 per cent.

In comparison with some of the Russian and American figures, yield increases due to shelter in the more humid parts of Europe are usually modest. There are exceptions: in Italy, for example, the average increase in 8 fields with eucalyptus windbreaks exceeded 25 per cent over 3 to 4 years. Observations made in Denmark and western Germany are more relevant to our conditions and figures published in Jutland plant-breeding journals between 1908 and 1925 showed increases due to shelter ranging from 6 to 34 per cent. For all cereals, shelter from westerly winds improved grain yields by 17.1 per cent and straw by 17.2 per cent; shelter against the east gave corresponding figures of 11.7 and 12.1 per cent. With shelter against the west, other excess yields were, in percentages:

Beet	23.2	Potatoes	16.9
Cabbage	13.4	Grass and clover	24.1
Turnips	6.5	Lucerne	21.5

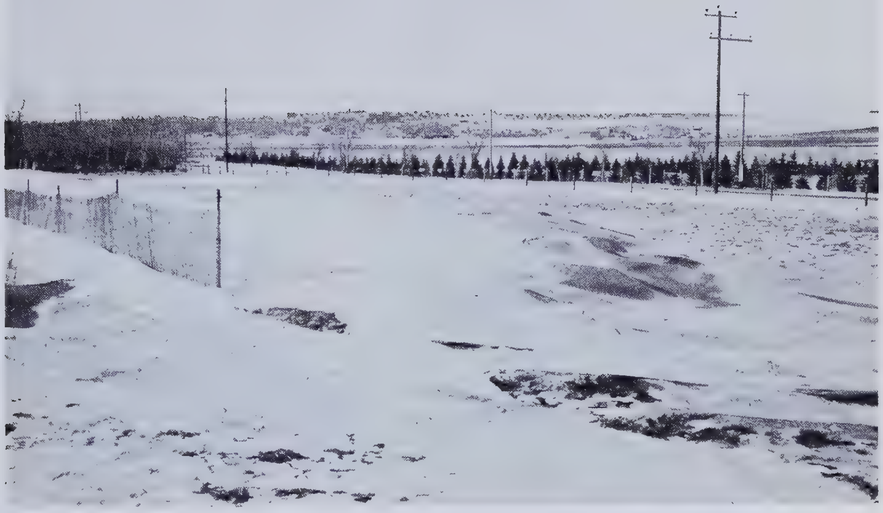
Turnips did better with shelter from the east (11.9 per cent increase) while potatoes fared less well (8.8 per cent increase), clover and grass mixtures showing roughly the same effect (23.3 per cent increase). Green-weight yields of grass tapered from 100 per cent, the yield at 3 'windbreak-heights' leeward, to about 80 per cent at 9 or 11 'heights' further down-wind.

Summarizing much of this information a few years ago, a Danish publication suggested that the increased yield due to shelter was four and a half times as great as the loss due to the location and edge-effects of a shelterbelt. This was followed by a Swedish calculation that, if shelterbelts absorbed 5 per cent of cultivable ground, there would be a 15 per cent overall gain if one reckoned on a 20 per cent yield increase. This last figure erred on the optimistic side and increases of 10 per cent or less are more likely. At the same time, it is unnecessary to devote as much as 5 per cent of the land to shelterbelts; in Germany the limit is down to 1 per cent for good arable land.

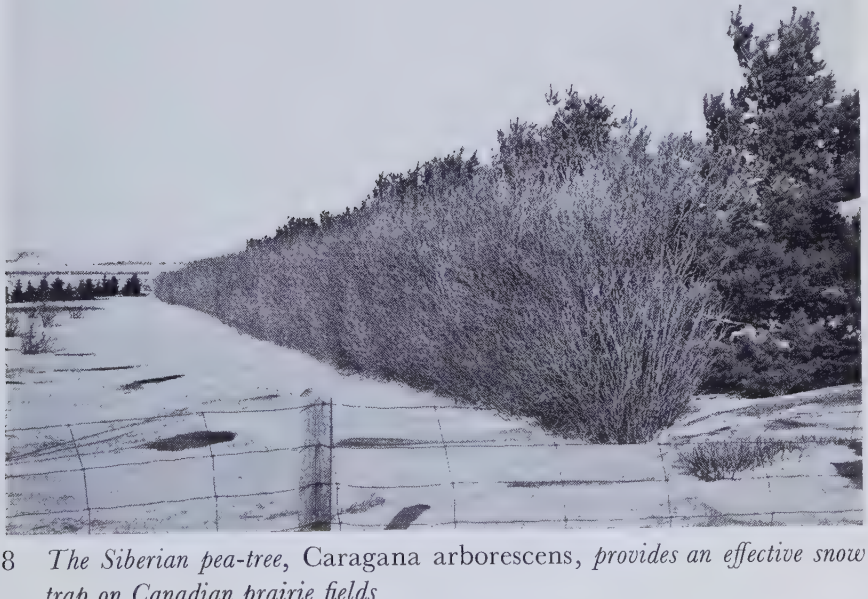
Detailed Danish studies by Dr. Martin Jensen, using rye-barley-oat mixtures, clover and grass, turnips, winter rye and a rye-barley mixture, have resulted in mean values of the yield improvement of 7 to 9 per cent where the wind was reduced by 68 per cent and 4.3 per cent where it was reduced by 37 per cent. The result obtained depends upon the wind distribution at different stages of a crop's development. In a German field experiment in 1955, oats on the west side of a windbreak averaged a 9 per cent increase in grain as far out as 30 'heights'. On the other side an oat-barley showed a 10 per cent increase in straw for a distance of 15 'heights'. Differences in straw in the oat crop and grain in the mixture were not significant, the explanation being that during May, in the young stage of the crops, winds were south-westerly, so that only the mixture was sheltered to any extent, leading to better straw development. In June, winds came from all directions, but in July, when crops were ripening, winds were easterly, so that the oats derived the benefit of the shelter, which was apparent in the grain yield.

Shelter affects not only bulk yields but also the quality of the produce. A recent analysis of Hungarian pastures sheltered by plantations has shown that total weight, dry weight, vitamin C content, digestible protein and starch were improved by 9, 67.8, 108.5, 144.4 and 85.2 per cent respectively over similar values for unprotected pastures, notwithstanding a rainfall of 46.5 per cent above the mean. In a dry season, the sheltered fields produced one-third of the normal spring yield, while most of the grass on exposed fields withered.

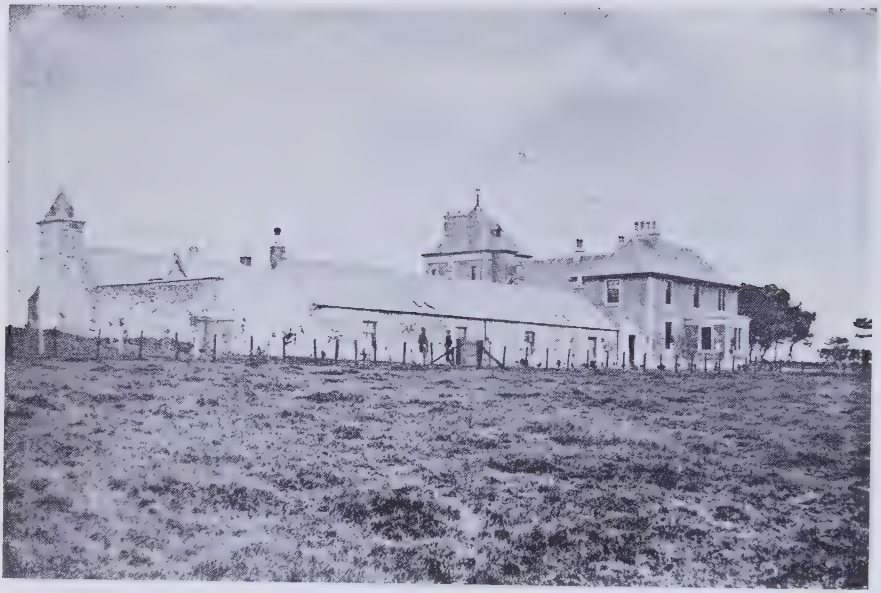
Surveying the evidence, it is still impossible to forecast an



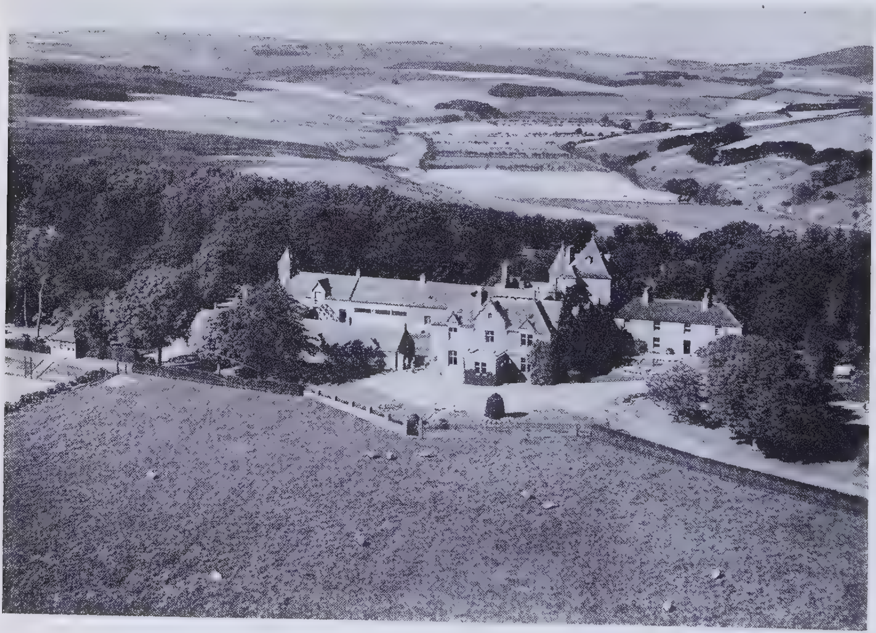
7 *A conventional snow fence in Saskatchewan showing drifts discoloured by blown soil*



8 *The Siberian pea-tree,* Caragana arborescens, *provides an effective snow trap on Canadian prairie fields*



9 *Whitchester House, Berwickshire, in 1881*



10 *Whitchester House, Berwickshire, in 1948, framed in sheltering trees. Plantations for livestock shelter on the hill pasture beyond*

average yield increase which shelterbelts might produce in a particular district in this country. Unfortunately, no controlled experiments have been undertaken in Britain on a field scale. On the horticultural side there is plenty of positive evidence. That shelter benefits farm crops is rarely disputed; the only difficulty is estimating the extent of the effect as a proportion of the average crop yield. The fact that shelter and good husbandry often go together makes it even more difficult to sort out the many factors involved, all of which contribute to the overall production. But the sheer weight of published records from overseas, and horticultural data obtained in this country, suggest that, where wind hinders plant growth or renders the local environment less than ideal for crops, the provision of shelter can raise the yields appreciably or, if not affect total output, get crops away to an earlier start, which may be equally beneficial. And, over much of the countryside, there is no doubt that wind conditions are sufficiently persistent as to affect the growth of vegetation; one has only to look at the trees to see this.

There is also the problem of wind erosion, small in Britain as compared with the situation in most European countries but serious enough where it occurs. Soil blowing in the spring is prevalent on the light soils of East Anglia and especially on intensively cultivated fenlands, where the sun can turn copper from the blowing peat. It occurs again in dry seasons on the Scottish lowlands and in the region of the Moray Firth. The abrasive action of driven soil and sand can cut crop yields considerably in a few hours, cause roots to be re-sown and sift freshly-applied fertilizers off the fields into hedges and ditches. The extent of the damage is not always apparent immediately but it can be a costly business. Although not in the nature of the ominous American dust storms, one of which in 1934 was estimated to have lifted 300 million tons of fertile top soil off the wheat plains, local blows experienced on the Norfolk breckland or the Cambridgeshire fens can be disastrous. Breckland is not as valuable as fenland, but insuring with trees against the disaster of a lost crop can be well worthwhile.

Wind velocities needed to initiate blowing depend on the soil but most winds over 10 m.p.h. can lead to soil erosion if conditions are ripe. Low air humidity encourages movement. In Aachen, which is at about the same latitude as Southampton or Tiverton, 10 per cent of all winds are reckoned to exceed the critical value for wind erosion. In Britain, the winds to do the damage are there should the overall weather and good husbandry fail, at some time or other, to provide adequate soil protection.

Checking soil erosion is a major world use of windbreaks, but they are not the only solution. Various cultural measures can reduce the erodibility of the soil: surface cultivation to replace ploughing; strip cropping; the maintenance of a trash cover or stubble mulch on fallow; marling and claying, which have been favoured in East Anglia and Denmark for generations. But shelterbelts are a second line of defence in that they break the force of eroding winds over a considerable distance. They are particularly valuable when other measures fail, as when a poor crop leaves insufficient stubble to stabilize the soil on prairie farms. To protect soils in eastern England, shelterbelts have a more limited appeal than hedges and other practices. Tree belts are expected to take up too much land. This need not be the case as has been shown recently in Westphalia, where erosion is a limiting factor to agriculture. Tall belts need occupy no more ground than, for example, overgrown hawthorn hedges a third of their height but will protect three times the area. It is not usually necessary to plant windbreaks so closely that all chance of eroding winds is eliminated; an average spacing between belts greatly reduces the risk and may be sufficient for most purposes.

For the reclamation of shifting coastal sands, shelter is indispensable and shorter intervals between windbreaks are advisable. A considerable acreage of land on the East Lothian coast has been brought into cultivation using sea buckthorn strips to provide the shelter. Carrots and other crops flourish in the sandy soil once the force of the wind is checked, and windbreaks have been the means of reclaiming valuable land once considered intractable.

Whether the frequency of soil blowing, droughts or cold, late seasons warrants the expense of shelter planting is a question only local knowledge and experience can satisfy. On the other hand, where land is exposed to a fairly high level of wind for most of the season the case for shelter is strong. Where it is less so, possible disadvantages of shelter planting must be noted. Many arable districts derive reasonable shelter from the topography, including landscape features such as hedges and woodlands. Some areas, like problem parts of the Weald, may be so hemmed in with hedges that the cold, wet land receives insufficient sun or ventilation and becomes unsuited to arable cropping. On heavy Midland clays, the disadvantages of slow drying-out in the spring may conceivably cancel out the advantages of shelter during the rest of the year. Too sharp a drop in the wind will lead to excessive moisture but shelterbelts should be designed to avoid this. Much heavy land in parts of Lincolnshire, for example, presently overstocked with hedges that are expensive to maintain, could be improved by replacing some of the latter with deeper ditches and a few well-planned shelterbelts to protect larger fields.

That shelterbelts harbour birds to prey upon farm crops is a traditional objection but the majority of birds frequenting such habitats are insectivorous and therefore beneficial. Some of the most troublesome do not live in shelterbelts; those that do are not difficult to control. Weeds can flourish in some shelterbelts and spread to adjacent fields, occasionally a problem in Canada and the United States. In our climate the problem is rarely important; narrow belts encourage the usual hedgerow species but, in the case of wider belts, where there is a better chance of developing a balanced woodland flora, agricultural weeds fail to prosper and woodland 'escapes' are not fitted to withstand ecological conditions in open fields. More important is the fact that wind-dispersed seeds tend to be deposited near shelterbelts, thistle particularly, but modern weed-killers can control the situation and some can be used with safety beneath established trees. Leaf fall on pasture adjacent to shelterbelts can also create a nuisance but this can be kept in check by restricting the proportions of species with foliage that decays slowly, such as beech.

Certain tree and shrub species act as primary or secondary hosts for fungal and insect pests, such as the wheat rust which alternates between barberry and cereals and certain of the migratory aphides. In Britain, attacks of this kind are not serious from the farmer's point of view. The preference shown by some biological agencies for the micro-climate of sheltered areas may be of greater significance: mice, for instance, or fungal diseases which like warm, moist conditions. On the other hand, pollinating insects are more active when protected from boisterous conditions.

Cereals grown in shelter have a greater tendency to fast growth, resulting in mechanical tissues in the straw being less developed than normally. Although longer straw with diminished strength implies greater susceptibility to lodging, this is more than off-set by the lower winds that hold for sheltered areas. The exceptions are when belts are too dense and cause violent eddying in their lee or when crops are suddenly subjected to a gusty wind from a direction against which the belt offers no protection. It is not uncommon to see a trail of laid crops where the wind has been deflected along the edge of a shelterbelt. Penetrable belts reduce the risk but without all-round shelter for fields this disadvantage cannot be overcome entirely. However, the chances of this occurring are not high and the possibility of loss even smaller.

5 Shelter and Livestock

Plants portray very readily the extreme affects of exposure. With livestock it is a different matter. The benefits or lack of outdoor shelter are not easily observed in the case of domestic animals, and assessment of their extent is even more difficult. But a comparison between cattle grazing contentedly near a shelterbelt or tall hedgerow on a really raw, windy day and another lot nearby bunched together with their backs to the wind suggests the truth of the old saying that cattle and sheep, whose bodies are not pierced by those sharp, keen winds of spring, autumn and winter, are able to feed better and thrive more readily. More than a century ago, J. C. Morton wrote in his work *On Soils* that 'cattle, if well sheltered, will thrive and grow fat on one-tenth less food than those which are exposed. If a tenant can raise 11 cattle instead of 10, then this explains why he can give more rent for sheltered pastures'.

The *Transactions of the Highland and Agricultural Society of Scotland* reported in 1874 that 'all intelligent farmers know the reason why stock decline so rapidly from exposure is that the carbonaceous food, which would otherwise go to the support of their bodies, is consumed in keeping up their animal heat'. Playfair's address to the Royal Agricultural Society in 1842 had illustrated this point. Experiments by Lord Ducie at Whitfield in Gloucestershire supported the theory. One hundred sheep were housed in a shed from October to March and fed on 20 lb of swedes each per day; another hundred were kept outdoors and ate 25 lb per day. After the winter, the sheltered sheep, in spite of a fifth less food, weighed 3 lb a head more than the others. This was at a time when indoor feeding of sheep enjoyed a brief revival of the medieval monastic practice of winter housing. One can assume from Morton's remarks that the results would have shown a similar trend had both flocks been fed outdoors but one kept within the shelter of a plantation; Morton was Lord Ducie's land steward and likely to have been concerned with these and possibly further experiments.

A century later, it was found in Montana, U.S.A., that a herd of cattle protected by a tree and shrub plantation gained 34.9 lb per head more during a mild winter and lost 10.6 lb less a head in a severe winter than another herd on a more open feed-lot. Similarly, cattle on a South Dakota pasture sheltered by natural tree and shrubby growth along a stream lost 30 lb per head less than a similar herd on a bleak pasture. A survey of farms in Nebraska and South Dakota has revealed substantial reductions in feeding stuff costs through providing shelter: 86 livestock feeders valued their annual savings at more than 800 dollars, 62 breeders at more than 500 dollars and 53 dairymen at more than 600 dollars. Without knowing the herd sizes in question it is impossible to rank these figures as a percentage of total costs. However, it is accepted that in cold weather an animal requires more nourishment to balance the considerable loss of heat. At the British Society of Animal Production meeting in Edinburgh in 1958 it was explained that to maintain sheep in a very cold environment required rations high in metabolizable energy.

The condition of the animal's coat is important too. In field trials conducted by the Hannah Research Institute in the 1956–7 winter, Blackface wethers in full fleece did not lose weight compared with a similar group housed indoors at a temperature of 55° F. Doubts have been expressed that sheep under exposed conditions grow thicker or longer fleeces and it has been suggested that a warmer environment may be conducive to a better fleece. Certainly, one Scottish shepherd in 1857 held that sheep in sheltered situations produced a better quality of wool.

Whether this is true or not, breeds of cattle and sheep differ, for various reasons, in their reaction to climatic stress and hardiness and, consequently, in their attitude towards shelter. Cold, driving rain, which can cause acute discomfort to dairy breeds, may fail to disturb the composure of Welsh Black or Highland cattle. Likewise, some sheep are much more sensitive to changes in environment than others. One can assume, however, that an amelioration of the climate of exposed grazings, probably through providing adequate shelter, will reduce the metabolic requirements of cattle and sheep and result in better utilization of the calorific intake. Thus, the available food goes further, either in terms of bigger weight increases or allowing a heavier stocking at the previous level of nutrition. In both cases this means greater production per unit area of pasture.

Milk yields from dairy herds have been said to rise as much as 16 per cent once pastures are sheltered. Although a reasonable claim, it is difficult to confirm since dairy cows are usually fed a ration to keep up their milk. But it would most likely occur with hill cows. Shepherds recognize the falling off in ewes' milk under prolonged east winds in spring, partly through the withering of new grass and partly through a physiological reaction to the wind's cooling effect. These are primary and secondary effects of exposure and, experimentally, it is not easy to distinguish between the two. Little is known of the climatic conditions or combination of weather factors that cause distress to livestock and elicit a physiological response, other than the need for more or less food which now seems well recognized. Cattle and sheep withstand very low temperatures; prairie cattle out-winter successfully with temperatures going down at least to 35° F. below zero, even without casual shelter. It is the wind at such low temperatures that can prove disastrous.

Livestock exposed to the mild winters of the west coast of the British Isles are not unduly troubled by the frequent, strong, westerlies. Stock further inland, where temperatures are lower, are more prone to take shelter from time to time. But when cold, easterly winds appear in spring there is a greater need for shelter on the western seaboard. Driving rain contributes to the animal's discomfort. Insulation is important in that it largely determines hardiness. Thickness of skin, hair growth, structure and density of fleece and birth coat and capacity to move position or posture according to the weather all provide protection for sheep. Consequently, the need for extra shelter is often overlooked. But the animal's ability to insulate itself may be inadequate at certain times. Acclimatization is clearly a major factor. Also, chill winds after shearing cause serious casualties amongst sheep in New Zealand, due to their being suddenly deprived of their customary protection. This has led to a good deal of windbreak planting. The old Scottish practice of salving or smearing with a greasy compound was a form of insulation and subcutaneous fat also plays a part, so that the previous level of nutrition influences the animal's reaction to the onset of severe, wintry conditions.

Where out-wintered stock deteriorates in condition through exposure or lack of supplementary feeding there is a greater tendency to ailments and epidemics. Hard weather lowers resistance and casualties at critical periods like pregnancy, lambing time and subsequent early weeks can be distressingly high in some years, especially to the small farmer. Observations by D. T. Michael on mountain flocks in North Wales suggest that, in its contribution to morbidity and mortality, lack of shelter is associated with the severity and onset of metabolic disorders, enterotoxaemia, anaerobic infections, pneumonia and wasting diseases. The hazard assumes greater importance with restriction of grazing area and grassland improvement, the selection of earlier and more persistently growing strains extending the grazing season into inclement periods. The incidence of lambing sickness in two adjoining flocks under the same ownership illustrated the role of shelter during the storm of 7–12 April 1950: in the first flock, grazing to 1,250 ft with shelter available, 10 cases were reported amongst 295 ewes; in the second, grazing to 1,400 ft without shelter, 37 cases occurred amongst 232 ewes. A further survey of pregnancy toxaemia and allied disorders amongst sheep in the 1955 winter showed an incidence of 0.7 per cent amongst ewes having access to woods

(11 cases in 1,513 ewes) and 4.1 per cent amongst ewes denied such shelter (816 cases in 19,954 ewes). Other conditions of management and nutrition are involved but similar differences were also found between ewes in a flock gaining access to shelter and others in the same flock without such facilities.

According to Michael, increases in multiple pregnancies alone do not account for more cases of pregnancy toxaemia. The greater incidence of the disease in 1955 coincided with some weeks of snow and hard weather in February and March, which did not recur to the same extent in the next four seasons. Improvement of inbye land, the 'intakes', or 'ffridd' in Wales, assisted by subsidy under various agricultural assistance schemes, presents some complications. The sudden change of in-lamb ewes from natural hill grazings on to vastly improved swards ready for lambing may precipitate another group of metabolic disorders, lambing sickness or hypocalcaemic tetany, sometimes associated with hypomagnesaemia and enterotoxaemia. Another field trial in 1950 indicated the adverse effect of exposure as a contributory factor and the distinct advantage of shelter in relation to these disorders. Only 21 cases were recorded out of 376 ewes (6 per cent) where there was natural shelter but 79 cases transpired amongst 302 ewes (26 per cent) in a contiguous flock on exposed ground.

Food and shelter go hand in hand; scarcity or lack of one or the other leads to the same disastrous result amongst hill flocks in winter blizzards. The catastrophic losses in the 1946–7 winter are a stern reminder that over a long spell of bad weather shelter without food is of little avail. Some Border sheep farmers have devoted as much attention to providing hay-sheds for emergency feeding as to equipping the upland grazings with stone stells for shelter. The fact that a single storm in 1937 cost the lives of 1,000 head of sheep on a Berwickshire farm reflects the need for some such form of insurance against a recurrence. Four million head of sheep were estimated to have perished in the early 1947 blizzards and a survey of hill farms in northern England at the time revealed that 7 flocks which suffered losses of 46 to 64 per cent were hefted on high, treeless grazings.

Though lack of shelter was not the only factor contributing to this calamity, it played a big part. Shelter may even be necessary before hay can be fed to sheep; there have been cases in the Cheviots of waiting two or three days before the wind relented sufficiently to allow hay to lie on the hard-packed snow.

Snow surfaces are always cold; they reflect the daytime warmth that would otherwise reach the ground below and on calm, clear nights radiative cooling of the snow surface is intense. This leaves the cover of snow colder still. In-lamb ewes need frequent rest and present large surfaces to the cold air and colder ground. By morning, heat loss from the body to the sky by radiation and to the ground by conduction is considerable. Fleeces often freeze to the ground. Side or overhead shelter checks the cooling, screening off part of the sky against outward radiation. Even isolated trees and bushes, stone dykes and straw hurdles afford appreciable protection on quiet nights when radiation is the chief determinant of temperature. On nights with more wind or overcast skies, convection becomes the vehicle for heat loss and rain adds to the discomfort; again, shelter reduces the stress imposed by intense cold. The thaw brings relief but sometimes tempered by its own problems. Driving wind and rain or ground too sodden or deeply frozen to absorb the water can cause more deaths than the period of snow. Some Wold flocks in eastern England suffered heavily in 1939: ewes died weeks afterwards in giving birth to lambs long dead.

Shelter for livestock mainly concerns stock-rearing farms in upland or mountainous parts of the country. There is less need for supplementary shelter on lowland farms, where hedges and walls provide a refuge against the weather. Hill contours afford a certain amount of shelter for stock but usually insufficient to safeguard against the rigours of severe conditions or to enable improvement in the grazing and carrying capacity of the ground. Shelterbelts are a means of increasing the productivity of hill ground. Early growth of grass develops on the edge of a belt of trees or forest block, due to a changed ground climate and to a cumulative influence of the shelter. Sheltered patches draw the stock and are grazed intensively and manured fairly heavily, gradually favouring more protein-rich grasses. These patches are extended outwards as the animals move farther from the shelter to obtain the fibrous bulk that complements the richer feeding from near the trees.

Hard grazing improved the old shieling pastures, the dominance of heather and blaeberry giving way to grasses with low-seated growing points. It is this which gives the well-grazed green strip around shelterbelts on *Molinia* or heather hillsides. This serves another useful purpose as a natural fire barrier; liming and fertilizers speed up its development. A common objection to plantations in districts where heather burning or 'muirburn' is practised is that trees complicate operations. Muirburn plays a prominent part in sheep farming although condemned by many soil conservationists. On some ground it exhausts soil fertility in the long run, often removing the soil itself when burning on moderate or steep slopes precedes heavy rains. On Cairn o' Mount in Kincardineshire an accidental heather fire in late 1957 destroyed the vegetation over a large area; subsequent heavy rains washed out huge patches of thin, peaty soil to a depth of 10 or 11 inches, exposing the underlying rock. But objections to burning without alternatives are not enough. At present no real alternatives have been presented and there are cases where the proximity of young, coniferous forests makes hill graziers and landlords loth to burn 'white' ground and heather. In Northumberland, one hill grazing of heather, 2 to 3 ft high, carries only half the stock it did ten years ago because of this fear of fire spreading. Heavy applications of lime and the use of cattle can improve the situation on some rough grassland but this is more difficult on heather moor.

Extensive areas of hill land have been re-seeded in recent years; some have been maintained whilst others have tended to revert to type. Occasionally, the new pastures could be made more stable by the slight improvement in ground climate found near shelterbelts. Little is known at present of the primary effect of shelter on the botanical composition of grass swards, excluding the associated effects of grazing and manuring. An interesting experiment has been conducted near Heidelberg in respect of arable weeds, two plots being left untouched for a number of years but one enclosed by sheltering screens. Significant differences have arisen, not only in growth but also in the association of species present. Similar studies could be made with advantage on hill grazings of representative types. In the early part of last century, 400 acres of moor on Shotley Fell, west of Newcastle, were enclosed with high stone walls and the land kept in good heart. The soil being poor, stock made little progress on it and it was valued at no more than 6d. per acre. Then the central part of each field was planted up and subsequently cocksfoot was said to reach 3 and 4 ft and cattle prospered as never before. Improvement of the local climate was held to have helped in some degree.

Changes in vegetation *beneath* plantations are well known, especially to foresters. Many of the older Forestry Commission plantations on former heather afford a thick growth of grass underneath the trees where there is sufficient light. Some have already been opened to grazing, like parts of Kielder and Drummond Hill forests. The experiences of the fourth Duke of Atholl (1774–1830) in Perthshire are the classical example. Land which had been worth only 9d. to 1s. per acre before planting eventually yielded, after the thinnings of the first 30 years, summer and winter pasturage worth up to 10s. per acre. As a result of various experiments it was concluded that pasture under oak coppice, available for only 8 years in 24, was valued at 5s. or 6s. per acre. Grazing under Scots pine was worth not more than 6d. above the unplanted price; under beech and spruce it dropped in value, although the latter afforded excellent shelter and shade for cattle. Under ash, however, pasture values rose by 2s. or 3s. per acre and under larch to 8s. and 10s. The value of the improved pasture alone, independent of timber production, was considered then to be worth the capital expenditure of planting with a suitable species.

Much hill farming land has a low feeding capacity; with a more exacting climate this limits the use of less hardy but more productive classes of livestock. Well-sheltered hill land is in another category. Cultivation during the Napoleonic Wars went higher than today but these conditions are not likely to recur and any cropping is usually incidental, supplementing the pasture. So that the greatest contribution that shelter planting can make to hill areas today, apart from storm protection, is linked with farm management and the general pursuit of greater efficiency and increased production. This was described by Professor J. E. Nichols at the British Association meeting in 1951 as aiming at a reduction of stock losses or of checks to growth at susceptible periods, coupled with the keeping of larger numbers of better-grown stock, so that more stores of better weight and condition are marketable and fewer replacements are needed. Further, since the provision, conservation and more efficient use of winter feed are major problems, implying more intensive use of suitable parts of holdings, shelterbelts might be regarded primarily as aids to such intensification and their siting decided accordingly.

Consider, for example, the advantage of having one or two sheltered paddocks of 10, 20 or even 30 acres on the lower hill ground. These could afford intensive grazing for several weeks in the year, relieving pressure on inbye fields and forming a link between wintering quarters and the open hill. Management of a farm so equipped could prove much more flexible and productive.

To conserve winter fodder, some control of grazing has to be exercised. Portable folds were used for this as early as Anglo-Saxon times. Hay for winter feeding is still a scarce commodity in some districts. In olden times it was argued that enclosing with hedges was a foundation for livestock improvement, since sheltered fields would provide a hay crop and some winter protection. Hill paddocks, particularly those with a wood to break the wind, are highly prized by shepherds because they allow inbye fields to be freed early in the season. On many small sheep farms in Wales, ewes and followers stay far too long on home fields and aggravate the hay position. Hay could have helped considerably in the cold spring of 1958 to compensate for the shrivelled pastures of Cardiganshire and Montgomeryshire.

Often, the reason for lateness in leaving inbye fields is the absence of divisions between the higher and lower parts of the hill. The 'cross fence', favoured in parts of Scotland, is invaluable here. Without it, ewes and lambs have to be held on low-lying pastures before they can be allowed with safety on the open hill. The long-standing suggestion that plantations and tree clumps should be dispersed across lower hill slopes and joined by fences to separate wintering and spring ground from summer grazings deserves consideration. Early lambing, as advocated by Best in 1641, was also intended to lighten the pressure on hay fields.

Scottish and northern England hill sheep farmers lamb on the open hill, not on the inbye land. Shelterbelts prove useful here when sited near spots where flocks congregate at night. Many ewes lamb at night or in the small hours near their 'night camps' and bare hills, where the wind largely clings to the contour, offer little protection.

Hill land is characteristically understocked in summer and early autumn, due to shortage of wintering facilities. Grassland improvement, with greater surpluses in summer, accentuates the situation, sometimes needing extra stock to clear the excess. Properly distributed shelterbelts can extend the growing and grazing seasons and spread the benefits of re-seeding more evenly. Accessible shelter should the weather break allows stock longer at the higher elevations and is invaluable for sheep hefted on the hill all the year round.

The wintering problem is always prominent and the economics of grassland improvement appear to hinge on this question. Changes in land use may have worsened the position in some districts; the coastal areas of mid-Wales that formerly wintered Brecon flocks have changed to dairying. The autumn and winter glut of mutton stems from the lack of wintering ground. Movement of flocks from the hills to lower elevations is an age-old practice. Thousands of sheep left the Ettrick Forest hills for the comparative safety of Eskdale and Annandale, a fact deplored by Napier in his *Treatise on Store Farming* in 1822 as 'one of the most dangerous and unprofitable expedients which have ever yet been adopted through the blunders of pressing necessity' and one which he felt could be remedied by feeding at home. Rising costs of transportation, apart from the present pressure on lowland areas, make it an expensive business. Wintering at home calls for two things: supplementary feeding and protection against storms and bad weather. Shelterbelts help by providing better growth conditions for hay and crops in upland fields, by aiding the sub-division of the land in furtherance of management and by affording storm protection when required. The Whitchester estate in Berwickshire illustrates this.

Increases in hill cattle add to the winter feed burden and put pressure on steading accommodation. Overcrowding and over-heating can cause as much discomfort as lack of shelter and out-wintering has become more popular. In the milder districts, a few hedgerows for casual shelter may be all that is necessary for out-wintered stock. However, young spruce blocks on the Argyllshire coast have proved useful for feeding hay during windy weather, the hay being spread under the trees to prevent its being blown away. Galloway cattle also seemed to appreciate their protection during the odd wintry days. The need for shelter is more urgent on the east coast but how much this is worth during an average winter is not known. A farmer who has wintered Shorthorns outdoors on the Angus coast and found it successful has suggested that windbreaks would have made an appreciable difference. It is the severe winter that will decide.

Stock that has been out-wintered is undisturbed by a cold, windy period in spring; stock that has been in-wintered suffers an inevitable check. Acclimatized animals with thick, shaggy coats make better progress. The same goes for cattle that have had the most rudimentary of shelters, compared with others that have had more expensive, and often over-warm, accommodation. Open woodland offers ideal winter protection and large numbers of oak, alder and birch blocks are used as 'winterings' in Wales and Scotland. Cattle often prefer this type of shelter, even if draughty in small clumps, to open-fronted corrugated-iron and aluminium sheds.

Supplementary feeding and shelter are supposed to make stock less inclined to forage for themselves. Sheep sometimes hang too long in the lee of woodland, rather than test the weather farther out; but not all farmers and shepherds agree on this point. Over-used ground beside a shelterbelt tends to foul and thus increase the danger of worm infestation and other disorders. This is inevitable during long spells of bad weather; at other times good shepherding keeps flocks moving on to clean ground. Poaching and compacting can be serious on sticky clays and many plantation margins in Northumberland have suffered in this respect. Rushes have replaced the grass and cattle tracks along the fences have removed all vegetation. The only solution here is to provide longer lengths of sheltered margin to spread the load; over-use suggests the need for shelter.

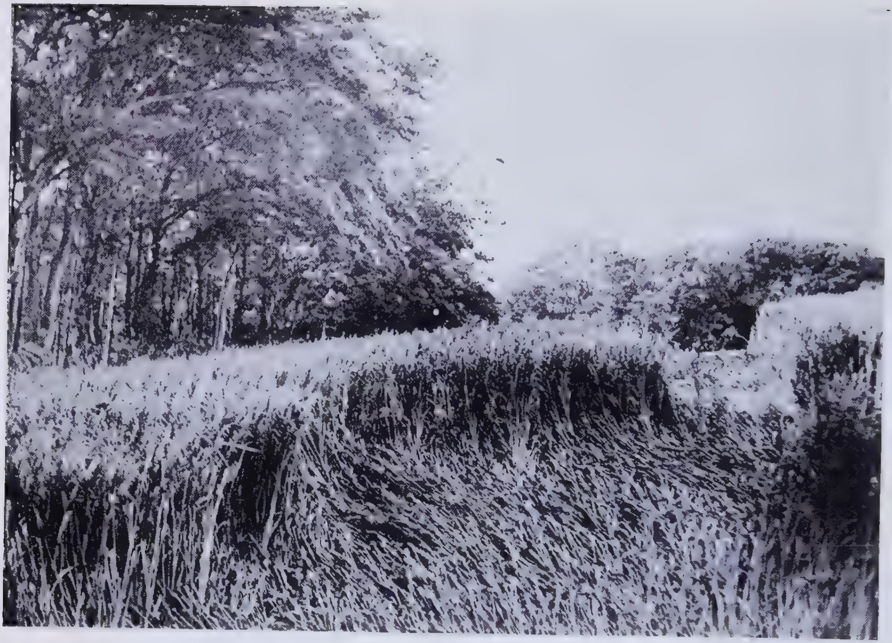
Long sprawling shelterbelts interrupt the view and complicate shepherding as well as restricting sheep movements. Ease of scanning wide expanses of hill is incompatible with shelter, whether the latter is due to relief or plantations. But belts can be sited so as not to interfere with the natural rake of sheep; walking over the ground with the shepherd concerned soon produces a suitable planting scheme. Fenced paths through long belts add to their cost but may also be justifiable. Alternatively, more compact blocks may supply the shelter most required.

Where catastrophic storms occur from time to time, arguments against shelterbelts are few. The advantage of storm protection on these infrequent but often disastrous occasions outweighs all other considerations. Farmers are reluctant to disclose such losses. If these figures were available and subjected to critical analysis, they would provide a valuable indication of the long-term value of shelter planting. But personal experience and judgment appeal more than a wealth of statistics.

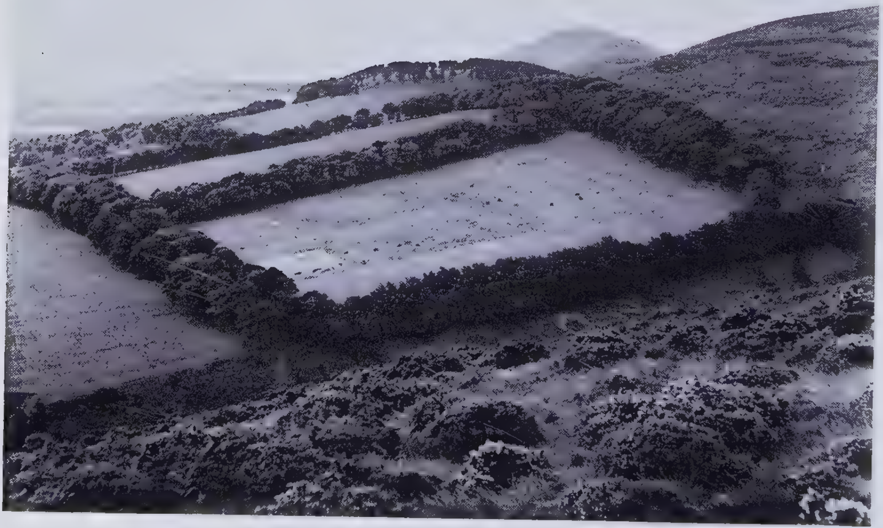
Configuration of land usually allows a certain amount of 'natural' shelter, especially close to the surface. Broken, rocky country, like much of the Scottish Highlands, affords a good

11 *Straggly growth of an old sea buckthorn windbreak near the East Lothian coast*

12 *Young, vigorous single-row windbreak of sea buckthorn in East Lothian. Regular cultivation is necessary to control suckering along the margins*



13 *Cereal crop flattened by a wind deflected along the margin of a shelterbelt*



14 *Sheltered paddocks on the Pentland Hills*

deal. Flat, lowland pastures derive their local shelter from other landscape features. But the smooth, rounded profiles typical of the Southern Uplands, the elevated plateau of mid-Wales and the gentle undulations of down and wold have little shelter in the form of the land. Leeward slopes with gradients less than 1 in 4 or 5 are readily followed by the wind; on Border hills there may be less shelter on the leeward aspects than is found where windward faces flatten out towards the crests of characteristically flat-topped ridges. Slight changes in gradient virtually lift the wind stream a foot or two above the surface, leaving a shallow pool of calmer air. Sheep draw to the tops to spend the night and it is these favoured spots that are often selected for 'night camps'. At first glance they may appear fully exposed to the wind; at the height of a man they may be. Such examples show that the fact that a tree is wind-twisted at 20 ft is no certain indication that a sheep at its foot is in need of shelter.

Most 'natural' shelter, however, lies in hollows and gullies, welcome enough during wind and rain but often disastrous in times of snow. For these are the places that attract drifting and into which sheep may be driven by a storm, probably overburdened by heavy, wet snow from the north-west if their fleeces are long or overcome by easterly blizzards of fine, powdery snow with its penetrating cold. This is why stells were sited in spots where sheep could find them readily or be driven in when snow threatened. They were placed convenient to areas where sheep tended to congregate but not where snow collected. Situations in hollows and ravines, on steepish slopes or below ridge crests were avoided; open ground or a slight eminence above a valley floor were preferred, to keep the ground around the stell blown clear of snow.

Hedges augment the 'natural' shelter as does low vegetation like broom, whin and bracken on the open hill and beds of nettles on improved pasture. Broom and whin were regularly planted for shelter and browsing during hard weather by olden shepherds, a practice now forgotten. Hill ewes seek out the shelter of old heather or tussocky grass for a brief respite in which to produce their lambs and recent observations at

Aberystwyth have demonstrated that sheep make use of the shelter of gorse patches and similar low cover when weather conditions dictate. Whether shelter of this kind is sufficient or not must be judged on the spot. Obviously, because of their height, cattle find less shelter in an upland field than sheep, just as root crops that lie close to the ground are less exposed than cereals. Thus, the local shelter that satisfies one type of livestock or crop may be inadequate for another.

Shelter introduced in the form of trees or hedges should extend the natural, topographic shelter available, in so far as farm and field boundaries allow. But gullies and ravines that are danger spots in snow are often better planted up completely unless they can be made safer with a shelterbelt. A shelterbelt sited so that the ground to leeward falls away with the wind gives good value and it is advisable to make belts complementary to some local feature like a ridge or spur. Multiple belts may be arranged so that collectively they give better protection than they could individually. A grid or checkerboard pattern lends itself to mixed farming on uniform plains or upland slopes;

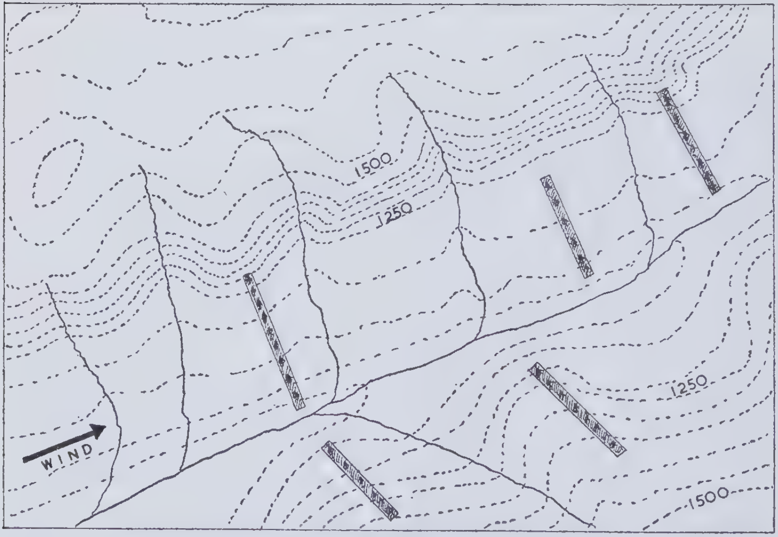


Fig. 14 Belts forming a series of 'baffle-plates' along a windswept valley.

belts running down on either side at frequent intervals, to form a series of 'baffle-plates', can transform the character of a windswept glen. Compact, planted blocks may supplant or supplement the long strip on many hill farms. Broken, rough country rarely lends itself to the traditional, long shelterbelt; changes in the contour may curtail the extent of its shelter. Scattered blocks at strategic points may be more appropriate, to furnish some protection whatever the wind direction, although winds surging round the ends limit the zone that is sheltered the more cross-wind dimensions are restricted.

Possible shapes for plantation blocks are endless, from diamonds, squares, 'kidneys' and crosses even to letters like the 'B' on the eastern slopes of Plynlimmon in Wales. The circular block affords the least efficient shelter but has the cheapest fence for its area. Fencing costs govern the shape in most cases and have given rise to the suggested 'Manx-leg' type, a three-legged block composed of squares superimposed on each of the sides of an equilateral triangle. It has the advantage of giving all-round shelter with little more fencing outlay than if the three squares were joined end to end to make one belt. It is a variation of the once-popular 'Maltese-cross', like the one which overlooks Edinburgh from the end of the Pentlands. Plantations in various forms were formerly combined with many stone-walled stells. The four-leaved clover design with four deeply-rounded bays for shelter is an example from Lanarkshire of an 'outside stell'; a rectangular stell surrounded by a shelterbelt, with exits angled to keep out the wind, an 'inside' type from Berwickshire. Expensive designs like these find few customers today but illustrate the width of the selection. The type of shelter adopted must fit the needs of the farm and situation and, usually, as simply and cheaply as possible. Then, it can pay dividends.

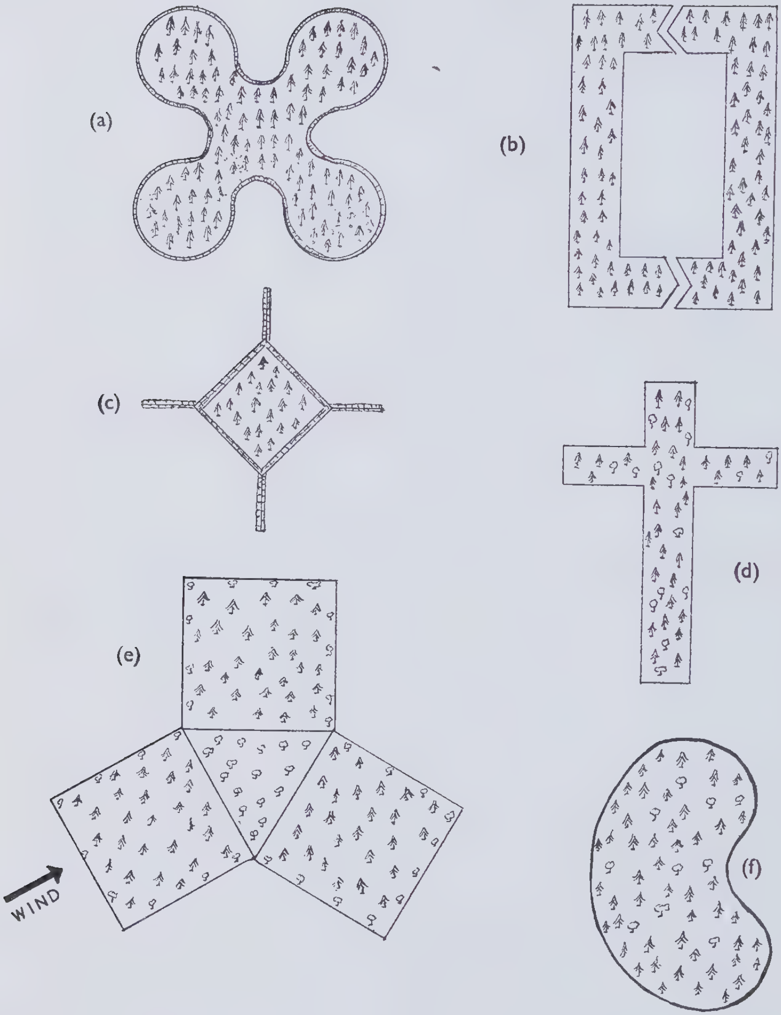


Fig. 15 *Shelter plantations for livestock. (a), (b) and (c) are nineteenth-century Scottish examples of stells combining plantations; (d) and (f) are examples of the various shapes adopted for hill planting; (e) Cadman's 'Manx-leg' plantation, affording protection against all quarters.*

6 The Sheltering Trees

Trees to plant in farm shelterbelts and smaller windbreaks elsewhere deserve careful selection. Mistakes can last a long time or else lose years of valuable shelter. Trees out of tune with their environment cannot give of their best; some flourish in youth but, due to a deficiency of some element or other as demands grow, fail to reach maturity or attain good form or size. They need to suit the soil and climate and, on windy sites, to achieve an anchorage appropriate to the abnormal pressures of winter gales. Species to reach full height or make worthwhile timber require most attention. Temporary species, grown for quick shelter or as a foundation to be succeeded by something more permanent, are less exacting but need to respond to their surroundings if they are going to give value for money. Good foresters plan their plantations to fit, or effect a reasonable compromise with, the local ecology; the same should apply to windbreaks planned for permanency.

There can be no simpler or more useful guide in choosing species than to observe those that succeed in similar situations in the district and on comparable soils. They are a better indication than notes in a nurseryman's catalogue. This policy may, of course, be unfair to a species if poor examples have resulted from inferior seed or neglect but generally it works well. Intelligent planters, prepared to purchase proven stock and spend time on initial establishment and maintenance of garden windbreaks, can afford to be more ambitious in their choice. But plants that prosper under cultivation and care in gardens are infinitely more than those which adjust to harder conditions in farm shelterbelts.

Broad-leaved trees, particularly those that yield valuable timber, are mainly suited to the deeper, fertile soils of the lowlands and lower hill slopes, whilst conifers are generally more tolerant of exposed hill ground and poorer, acid conditions. Such statements need qualification; there are exceptions on both sides. Hardwood forest is the natural climax vegetation of most of the British Isles, the Scots pine, yew and juniper being the only indigenous representatives of the coniferous tribe. So that most cases allow the use of both broad-leaves and conifers to some extent, the emphasis on one or other varying to suit site and other requirements.

Purely coniferous shelterbelts of even age and height are excessively dense in youth, after which they thin out in the trunk space and are difficult to regenerate without heavy fellings. As single-row windbreaks, staying clothed to the ground, some species satisfy needs in gardens and fields that are not too exposed. Hardwoods commonly throw up coppice shoots when cut back to stumps and permit density to be regulated and stands perpetuated much more readily, whilst a richer, more abundant ground vegetation below gives better shelter near the ground. The deciduous majority lose their leaves in winter, an advantage on arable ground and in wet gardens that dry out slowly in the spring. Therefore broad-leaved species with conifers can be beneficial, even on the poorer soils and exposed upland sites, where conifers form the bulk of shelter plantations. A proportion of hardy, wind-firm broad-leaves adds strength and stability and assists later generations to preserve the shelter. Equally important, an admixture of evergreens with deciduous trees ensures better winter shelter.

The selection of species should be based, first of all, on the type of windbreak required and whether large, medium or small trees are necessary for the purpose. It is pointless planting major forest trees in cramped quarters; less lofty species can grow as quickly and be retained much longer. Note should also be taken of tolerance of atmospheric conditions such as wind, frost, salt spray, air pollution and general exposure, as well as the preference of the species with respect to soil type, fertility and drainage. Rate of growth and light requirements are also important and, for those concerned with timber potentialities, the usefulness of the timber and produce from thinnings, yield as compared with alternative species and suitable rotation on which to grow the timber. These last points regarding the economics of timber production in plantations are, however, beyond the scope of this book,* but are mentioned briefly in Chapter 11.

The following notes refer to trees and shrubs commonly encountered and readily obtainable from most forest tree nurseries. They are intended to show the broad requirements of individual species and serve as a guide to a suitable selection of material. For farm and estate shelterbelts these species provide a choice adequate for most purposes. For gardens, parks and ornamental uses can be added a considerable variety of possible species, as an alternative or supplement to those mentioned. Examples are given in Chapters 7 and 8. Further information is contained in the Appendix (pp. 276–81), in order to assist the selection of the most promising trees and shrubs for particular situations.

MAJOR TREE SPECIES—CONIFERS

Pines:

The native Scots pine (*Pinus sylvestris L.*) is an adaptable tree, tolerating a wide range of conditions, but does best on dry heather sites and light glacial sands and gravels. It fails to thrive long on chalk and limestone soils, soft ground and wet moorland but occasionally forms a tall tree on stiff clays in eastern England. It is very wind-firm but becomes windswept at high elevations, where it may suffer severe snow break in hard winters. It dislikes sea winds and smoky conditions. Frost hardy and a strong light demander, it casts dense shade when young but allows underplanting when older. Its valuable, red deal timber has many uses. It reaches 70–100 ft on good sites, growing up to 18 ins. per year for the first 50 years; growth on poorer ground may be less than half of this, especially in the early years.

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* See, for example, W. E. Hiley's *Economics of Plantations*, Faber & Faber, 1949.

Corsican pine (*P. nigra* var. *calabrica* Schneid., syn. ssp. *laricio* (Poir) Palibin) prefers light, deep, sandy soils in lowland districts and even heavy clays in low-rainfall areas of south and east England. It is also more tolerant of chalk soils than Scots pine, liking moderately base-rich sites. It withstands sea winds but not salt spray on sea-fronts and is unsuited to soft ground, high elevations over about 800 ft and northern, upland districts. Wind-firm and frost hardy, it is also a light demander, casting heavy shade. On most suitable sites, growth is quicker than that of Scots pine. It can attain 80 ft in 50 years and even poorer qualities should average 12 in. per year. The timber matures more slowly than with Scots pine and is of poorer quality.

Austrian pine (*P. nigra* var. *austriaca* Asch. Graeb., syn. ssp. *nigra*) is an excellent shelter tree for exposed situations near the sea and on light, dry, shallow soils, sands, chalk and limestone but less suited than Corsican pine for infertile and stiff or wet soils. It is very wind-firm, frost hardy, light-demanding and withstands polluted atmospheres. The rate of growth is similar to that of the Corsican variety but its habit is more bushy in youth, presenting a coarser appearance and poorer stem form, which severely limits its timber value.

Pinus contorta Dougl. covers the sometimes distinguished shore or beach pine and the lodgepole or Murray pine, varying from a bushy tree, 10–30 ft high, to a tall tree of 70 ft and upwards, so that the seed source is important. Lodgepole pine succeeds on poor heaths and difficult, wet peats where other species fail. It withstands considerable exposure but may suffer wind-blow on deep peat unless in mixture. It is frost hardy and is well suited as a pioneer or nurse on the poorest sites at high elevations. It is light demanding but stands a little shade; also resists sea winds. Growth compares roughly with the best of Scots pine but that is for lodgepole pine under the exacting conditions to which it is usually confined. Its timber has not yet been widely marketed but is somewhat inferior to Scots pine.

The mountain pine (*P. mugo* Turra) varies in habit from the more upright var. *rostrata*, which only rarely forms a tall tree, to the even bushier var. *pumilio*, which never does. It grows very slowly, often less than 6 in. per year, but is extremely wind-resistant, succeeding under the severest tests of climate and soils. It is frost hardy and very useful as an outer fringe for high-elevation shelterbelts or as a pioneer on infertile ground above the normal planting limit for most species. It has no timber value.

The maritime pine (*P. pinaster* Ait.) is frost tender and restricted to mild districts, thriving in exposed maritime situations in south and west England on sandy soils. It grows quickly when young, outstripping Scots and Corsican pines, and the fastest grown specimen recorded reached 100 ft in 80 years in Cornwall. Stems tend to curve and timber prospects are poor.

The Monterey pine (*P. radiata* D. Don) is again a tree for deep, well-drained, siliceous soils and sands with a mild climate. It withstands salt-laden winds and is wind-firm, being also light-demanding with heavy foliage. Early height growth is rapid: in 25–30 years trees may attain 50–70 ft, after which the rate declines. Several specimens over 130 ft are known but the coarseness and knottiness of the timber reduce the value. For quick shelter on mild coasts the Monterey pine warrants consideration.

Larches:

The larches are the only deciduous conifers of importance. The European species (*Larix decidua* Mill.) demands moist but porous, well-drained, moderately fertile, loamy soils. It prefers a dry to a moist atmosphere, which with frost and poor drainage encourages ‘die-back’ and canker. Drouthy or badly drained sites, thin soils over chalk and peat, less fertile grassland and heath, frosty sites and coastal situations need to be avoided. Long sunlight suits it but southern aspects that increase frost risk or dry out too readily can be a disadvantage. Open but not exposed situations are desirable; windswept sites are unsuitable. On suitable sites in lowland and upland it stands a fair amount of wind and forms a useful windbreak but, although wind-firm, larch needs to be used in mixture with other species, preferably in groups, for more exposed places. It should never occupy the margins of hill shelterbelts. On good sites it tops 20 ft within 10 years and 80 ft after 50 years; poorer qualities should average 12 in. per year. Larch growth tapers off more than in pines. Its valuable timber is well-known and the most useful for local farm and estate purposes. European larch is not recommended for smoky localities.

The Japanese larch (*L. leptolepis* Murr.) grows faster, is less subject to disease and thrives over wide conditions, including the wetter, humid uplands of the north and west. It suits heavier soils and tolerates poorer conditions than the European species, even grass and heather slopes, but is less satisfactory on chalk downs although it succeeds in loams over chalk and limestone. Very dry sites in low rainfall areas (less than 30 in.) should be avoided and soils of low fertility. It resists moderate exposure, is fairly frost hardy and a useful nurse species for early shelter, but where exposure is considerable it leans and twists badly. Small plants are important for such situations but Japanese larch needs side protection in high-lying shelterbelts. Growth may average up to 2½ ft annually for the first 20 years, slowing down later but probably attaining 90 ft after 50 years. Even in the poorest situations in which it becomes established it should average 12 in. per year. Its timber is regarded as slightly inferior to that of European larch but it withstands smoky situations better if the soil and climate suit.

The hybrid or Dunkeld larch (*L. eurolepis* Henry) combines the vigour and canker resistance of its Japanese parent with the better stem form of the European. It does better under poor and exposed conditions than Japanese larch and has shown promise on peats and upland heaths. On European larch sites it is often preferred for its freedom from 'die-back' and quicker returns. Only first and second generation hybrids from selected parents ensure these qualities; growth and volume increment should then parallel the best of the Japanese larch. The timber occupies a position intermediate between that of its parents.

The Siberian larch (*L. sibirica* Led.) is valuable for shelterbelts in continental climates, tolerating severe winters and short growing seasons. Unfortunately, its early flushing under British conditions renders it highly susceptible to late spring frosts.

Spruces:

The Norway spruce (*Picea abies* Karst., syn. *P. excelsa* Link.) is an accommodating species, successful on moist, grassy or rushy land and even shallow peats and most reasonably fertile soils, including fairly heavy clays. It fails on dry sites and shallow soils liable to dry out in exceptionally dry weather should be avoided. It also checks seriously on heather. Its shallow rooting tends to encourage wind-throw but less so on moist, porous ground. In exposed situations on high land and near the sea it suffers blasting and browning of the leaves. It is somewhat frost-tender and a moderate shade-bearer, valuable for underplanting if allowed light early in life, and especially valuable for mixtures with hardwoods. City sites and polluted atmospheres are unsuitable. Growth on good sites may be 18 in. or more per year, to give 80-ft trees at 50 years but it may be slow to start. Its timber enjoys many uses; in addition, tops and small trees find a remunerative Christmas market.

Sitka spruce (*P. sitchensis* Carr.), a valuable shelterbelt conifer, is easily established in damp and exposed situations and thrives on peats and acid grasslands in high rainfall districts of the north and west. Infertile peats are less suitable and frosty or very dry sites and heathery ground should be avoided; a rainfall of less than 35 or 40 in. is usually inadequate. It fails on chalk and limestone soils but succeeds on sands with a high water-table in Denmark, where it is much used as a windbreak species. It withstands exposure well and is more wind-firm than

Norway spruce although liable to wind-blow when older on wet ground and peats. Sitka spruce is also more light-demanding and more frost-tender than Norway spruce but stands smoke and exposed situations not far from the sea more readily. Though likely to remain the most prominent species for hill-farm shelterbelts, it is better supported by more permanent and more stable species, for which it provides quick shelter. It grows fast under conditions that suit, averaging up to 2½ ft per year in the first 20 years and reaching heights up to 110 ft in 50 years. The timber is somewhat inferior to that of Norway spruce but volume yields are much greater.

The Serbian spruce (*P. omorika* Pančić) is similar to Norway spruce in its requirements but tolerates poorer soils on moorlands and peat and may prove useful on calcareous sites, where it succeeds as a screen and withstands considerable wind. It is less subject to frost damage than other spruces and less exacting as regards moisture; it is also more tolerant of town conditions than most conifers. Fine specimens exist in various districts but on sites that suit both its growth is generally slower than that of Norway spruce; on poor ground it does better than Norway spruce. Little is known of its timber at present.

White spruce (*P. glauca* Voss.) withstands considerable exposure in hill country, where it has been used occasionally for the edges of high-lying shelterbelts, and on Danish heathlands, where it was popular for windbreaks. It is not exacting as regards soil but grows slowly, often little more than 6 in. per year, and in both cases is being supplanted by the more vigorous Sitka spruce.

Douglas and Silver Firs:

The Douglas fir (*Pseudotsuga taxifolia* Britt., syn. *P. menziesii* Franc.) is a wind-sensitive species for the interior of wider, productive shelterbelts, never for margins, for restocking scrub hardwood belts, thinned coppice and suppressing cut-back rhododendron, because of its shade-bearing qualities and fairly high resistance to honey fungus. It prefers moderately fertile, porous loams with a good deal of rock debris in the wetter, western districts. Growth is lush on fertile sites, slower on lighter soils and sand overlying chalk, but establishment has been successful on deep peat, peat over glacial drift and some *Calluna* heaths, given intensive ground preparation and phosphates. Sheltered slopes on lowland and upland are best but leading shoots are lost once topographic shelter is outgrown; similarly, trees suffer when they outstrip their protective neighbours. Valley bottoms are prone to frost and liability to windblow is a further disadvantage on any soft ground. The home-grown timber is a useful general purpose softwood, inferior to its imported counterpart, but popular for estate work. Growth of the best quality is similar to that of the best Sitka spruce, averaging up to 2½ ft for the first 15–20 years and reaching up to 110 ft in 50 years. Trees up to 180 ft exist in this country.

The European silver fir (*Abies alba* Mill., syn. *A. pectinata* D.C.) requires moderately fertile, deep soils, even stiffish loams and limestone soils in the moister regions, but is unsuitable for sandy soils that dry out or peats. Heat requirements are modest and it does best in Scotland, where it can be used at moderate elevations, being wind-firm and resistant to exposure once established, even fairly near coasts. When young it is frost-tender, needing nurses for success in the open and usually employed for its shade-tolerance to underplant scrub and coppice. Like all silver firs, it does not tolerate atmospheric pollution and aphis damage restricts its wider use. The timber is a medium quality softwood. Initial growth is slow, thereafter better, averaging up to 18 in. per year over the first 40 years; trees over 120 ft are not unusual.

The giant or grand silver fir (*A. grandis* Lindl.) stands lower winter temperatures and drier conditions rather better, although responding to higher rainfalls above 40 in., but is less tolerant of exposure. Fresh, moist soils are preferred but it succeeds on moderately fertile, lighter soils. Chalk, heavy clay, peat, acid and low-fertility sites and frost hollows are best avoided. Another shade-bearer, it is useful for underplanting or restocking old hardwood belts. It is more wind-firm than Douglas fir but less so than the European species. Growth can be very rapid, probably 2½ ft annually, to reach heights of 120 ft after 50 years. The timber is slightly inferior to that of *A. alba.*

The noble fir (*A. procera* Rehd.) is more frost-hardy, withstands considerable exposure and is fairly wind-firm, therefore suited to high elevations with poorer, more acid soils too dry for Sitka spruce. It is less tolerant of shade than *A. grandis*, may also suffer in spring frosts and is liable to breakage when older through heavy cone-bearing; on some dry sites it may prove short-lived. Early growth tends to be slow but can average 15–20 in. per year eventually at elevated places in humid districts.

Of the Japanese silver firs, *Abies veitchii* Lindl. also grows vigorously in the west and north and appears to thrive better than most firs in the vicinity of towns but is unsuited to chalky soils though relatively resistant to spring frosts.

Western Red Cedar:

The western red cedar (*Thuja plicata* D. Don.) likes deep, fresh soils and shallow soils over rock in mild, moist regions, where it displays greatest vigour, but is also useful on heavy, base-rich soils in other districts. It succeeds on drier sites on chalk formations and thin sands over chalk as well as peat, given initial nursing. Deep, loose sands, very dry places and very acid conditions are unsuitable. It has a place on shelterbelt margins or for single-row windbreaks branched to the ground, being fairly wind-firm and resistant to spring frosts when older, but is not for very exposed conditions or polluted city atmospheres. It is used for hedges even fairly near the sea. Growth on good sites may exceed an annual average of 2 ft for the first 20 years, early growth often topping that of Douglas fir, Sitka spruce and *A. grandis* although these win eventually. Trees over 100 ft are common. The light, durable timber is valued for estate purposes.

The slower-growing, hardy *T. occidentalis* L. from America and the smaller *T. orientalis* L. from China, with their many varieties, are mainly of ornamental interest, although the former is also used as a hedge on wet soils.

Cypresses:

Lawson or Lawson's cypress (*Chamaecyparis lawsoniana* Parlat.) does best on deep, fertile soils in moist climates but tolerates a variety and has succeeded on some peats and heathlands. But it is not a species for hill ground generally although reasonably wind-firm. Under less exposed conditions it forms useful screens clothed to the ground. Standing shade well, it is good for underplanting and game coverts. A marked tendency to forking often favours snow-break and reduces timber values; the timber is used for general purposes, mostly indoors. The tree is moderately frost-hardy and fairly tolerant of atmospheric pollution but not very smoky conditions. Height growth is fairly fast but not rapid: 18 in. per year for the first 20–30 years is extremely good, trees attaining about 60 ft in 50 years. Many ornamental varieties are cultivated, of which the pyramidal var. *Allumii* is a favourite.

The Nootka or yellow cypress (*C. nootkatensis* Spach.) grows slowly at first but with promise for higher elevations than Lawson cypress and poor mountain soils, withstanding exposure and frost fairly well. Cold, gravelly but moist soils are suitable and thin soils over limestone have been planted successfully. Height growth is usually less than that of a Lawson cypress.

The Japanese species, *C. obtusa* and *C. pisifera* Endl., the 'Retinosporas', are noted for their remarkable range of ornamental varieties, mostly retaining juvenile foliage. These can adorn the inside margins of garden and park windbreaks.

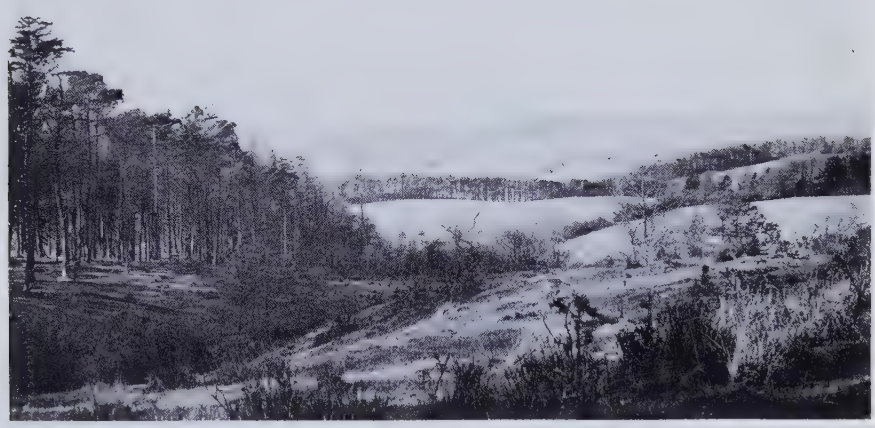
The Monterey cypress (*Cupressus macrocarpa* Hart.) withstands severe exposure to sea winds but only in mild districts of the south and west. It is susceptible to winter cold but spring frosts are less troublesome. Most brown earth soils are suitable, even chalks and sands near the coast, but acid conditions need to be avoided; it is wind-firm on drier sites. As a hedge it grows too fast and may not respond to hard pruning, especially when the climate is marginal for the species. It is fairly tolerant of town conditions but not heavy smoke. Annual growth on good sites may approach 2 ft over the first 20–25 years and maximum heights 60–70 ft. The timber is not of particular value.

The hybrid *Cupressocyparis leylandii* Dall. from the Nootka and Monterey cypresses is one of the fastest growing conifers and has shown remarkable vigour under varying conditions, averaging 2 ft or more in growth each year. Trees over 60 ft are found and one of the original hybrids attained a height of 90 ft after 44 seasons. Propagation is entirely from cuttings and a good root system is essential before the plant catches the wind. It is popular for hedges and quick-growing screens.

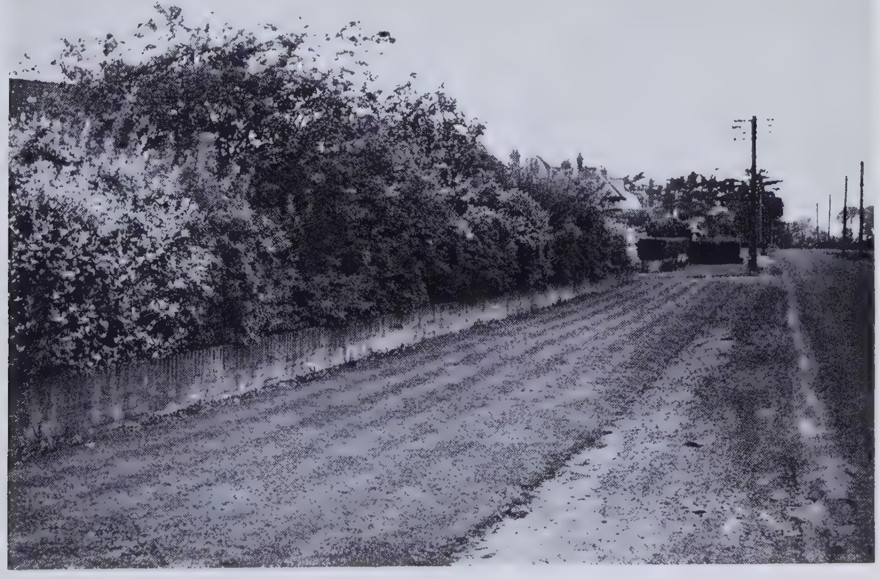
Western Hemlock:

The western hemlock (*Tsuga heterophylla* Sarg.) prefers higher rainfall areas and well-drained, non-chalky soils of fair depth and reasonable fertility on the lower slopes, disliking dry, loose sands. It has proved successful on moorland peat and, with nurse species, on poorer, drier heaths, requiring shelter in early years against frost and defoliation, caused by exposure; from both injuries it recovers fairly well. It is reasonably wind-firm, tolerating winds off the sea but not city smoke and withstanding heavy shade; a useful species for underplanting or for mixtures with hardwoods and other conifers to boost timber yields and to replace Douglas fir in improving scrub and coppice on heavier or less sheltered sites. Its pliant, turned-down leader is not readily broken by competing neighbours. The timber is a good softwood for general purposes and estate work and yields are heavy. Under first-class conditions trees should reach 100 ft in height after 50 years and some very tall specimens are recorded.

The eastern hemlock (*T. canadensis* Carr.) is mostly for ornamental uses, round-headed in appearance but marred by a bad habit of forking near the base. It grows well but not so vigorously as *T. heterophylla*, which it can replace on chalky ground and like which it is hardy, grows well in shade and forms a good



15 *Old shelterbelts in Wales providing overhead shelter for sheep in still, cold weather but little protection against wind*



16 *Informal shrubbery providing both screen and windbreak*

17 *Raspberry rows can provide local shelter for wind-sensitive crops*

18 *Espalier-trained apples give little winter shelter but make a fairly effective wind screen in summer*

hedge but dislikes smoky situations. A few trees exceed 100 ft in height.

Redwoods:

The redwood (*Sequoia sempervirens* Endl.) is mainly for ornament or avenues, older examples of the latter making ideal wind barriers. Deep, fertile soils are necessary, preferably in mild, humid districts. It flourishes only where levels of wind are modest, disliking exposure and frosty conditions. Well sited, growth is faster than with any other conifer and may be as much as 3 ft per year so that space must be plentiful. The Wellingtonia (*Sequoia wellingtonia* Seem.) does better than the true redwood in Scotland and is more tolerant of air pollution, exposure and soil conditions. Most non-acid soils suit, even rather dry and sandy types. It is reasonably wind-firm and used mainly for avenues and parks, where it may attain greater heights than the redwood; several trees exceed 130 ft.

Other Conifers:

The Japanese cedar (*Cryptomeria japonica* D. Don.) has lately shown itself to thrive under wide conditions, even moderate exposure at fairly high elevations. Most soils in wetter districts allow best development, growth sometimes exceeding 2 ft per year; under moderate exposure growth may still average 12 in. Tolerating considerable shade and coppicing readily, besides being a good volume producer, it is worth a trial in upland shelterbelts but good planting stock in quantity is difficult to obtain.

The hardy pencil cedar (*Juniperus virginiana* L.) prospers under various conditions in Britain but especially on chalk soils, tolerating town atmospheres and situations near the sea. Similar in growth to *Cupressus macrocarpa* but a more handsome, pyramidal tree, this species is most useful as a single-row windbreak to reach its full height of 30–40 ft or be kept trimmed as required.

The native juniper (*J. communis* L.) is a low spreading shrub or upright tree seldom attaining 30 ft in height. It occurs naturally on chalk and limestone and in upland Wales and the Scottish highlands. Once sown for local shelter on sheep walks, it is unlikely to be of future interest for shelterbelts except where it occurs locally.

The incense cedar (*Libocedrus decurrens* Torr.) provides a slender, columnar growth habit and rich colour, mainly as single specimens but ideal for relieving the leeside appearance of less interesting windbreaks. It can also be used as a screen or formal hedge, though slow-growing. It is hardy on moist, heavy soils and prefers well-drained loams in humid regions; it does not tolerate smoky conditions.

The native yew (*Taxus baccata* L.), sometimes growing to 50 ft but often no more than a bush, thrives on most soils but is particularly common on chalk downs. As a formal evergreen hedge in parks and gardens, out of reach of livestock on account of its poisonous foliage, it has few equals and its slow growth can be promoted by balanced fertilisers and well-rotted farmyard manure or compost. Its accommodating nature and extremely long life are advantages. The columnar Irish yew, var. *fastigiata*, is the most common of many ornamental varieties. All withstand dense shade and can maintain a permanent ground cover in shelterbelts not on farmland.

MAJOR TREE SPECIES—BROAD-LEAVED TREES

Oaks:

The pedunculate oak (*Quercus robur* L.) is a sound, windfirm, long-lived tree for incorporating in lowland agricultural shelterbelts, requiring deep fertile soils and growing well on fairly stiff and heavy clays and marls in the Midlands. Shallow, ill-drained or poor soils and exposed or frosty sites should be avoided. The sessile oak (*Q. petraea* Lieb.), slightly faster in growth, is typically a tree of mountainous districts of Wales and Scotland, on somewhat drier, shallower, siliceous soils rather acid in reaction. Deep porous soils suit and it does well on heavy clay and marl also, although wet sites encourage frost-crack. It is less frost-tender than the pedunculate oak and endures slightly more shade; both are light-demanding. Wind-firm and withstanding exposure well, the sessile oak is a valuable 'back-bone' for upland shelterbelts. Both species are difficult to establish in open, exposed situations and benefit from mixing, preferably by groups, with other species. Protected against deer and rabbits, oak on very suitable sites reaches 30 ft in 20 years, 60 ft in 50 and 90 ft in 100 years. Under poorer conditions annual growth may average only 6–9 in. Its valuable timber has many uses, price depending considerably on quality.

The American red oak (*Q. borealis* Michx.) demands less of the soil and has adapted itself to poorer acid and sandy or gravelly ground of fairly low fertility, growing vigorously. Limey soils are unsuitable. Hardy and more shade-tolerant than European species but less long-lived, its chief use is on sites marginal for better hardwoods and in mixtures, providing fine autumn tints. The timber is useful for general estate work but is not a substitute for European oak. On most soils red oak grows faster than native oaks for 20–30 years, averaging 15–20 in. per year and probably reaching 80–100 ft when mature but usually smaller than the indigenous species. It withstands town conditions.

The scarlet oak (*Q. coccinea* Munch.) is slightly less vigorous when young but also tolerates town sites and its less spreading habit is better for avenue belts, its brilliant foliage surviving late into autumn. Soil requirements are similar and good heavy loams have proved rewarding.

The Turkey oak (*Q. cerris* L.) is the most vigorous oak in southern districts and often elsewhere. Wind-resistant and moderately tolerant of atmospheric pollution, it thrives on strong deep loams and fertile soils even if shallow and suits a wide range, including clays and chalk. It forms a large spreading tree, up to 90 ft in height, but the timber lacks durability and working qualities, which may not rule out the species for moderately wide shelterbelts if limiting its forest importance.

The evergreen or holm oak (*Q. ilex* L.) for mild situations near the sea, grows slowly at first, somewhat better afterwards, and is well adapted to siliceous, sandy soils tending to acidity but also tolerant of warm, calcareous sites. It may be used as an ornamental or border tree in windbreaks, being very wind-resistant in the right climate. Favourable sites may produce tall trees to 70 ft and a tree in Norfolk reached 50 ft in 36 years; under less suitable conditions it may remain a bush but healthy except in cold winters.

Beech:

Beech (*Fagus sylvatica* L.) accepts various soils but is specially suited to chalk and limestone. It is not native to northern Britain but widely planted, preferring mild climates but withstanding severe exposure elsewhere. Waterlogged areas, heavy marls and infertile sands are unsuitable. Wind-firm on all but shallow soils, frost-tender but bearing dense shade, it is invaluable for underplanting or in mixtures, yielding low cover and improving the soil. On account of its dense shade, it should never become dominant in shelterbelts; old beech belts are open and draughty at the bottom and difficult to regenerate. It is excellent for belt margins, even on exposed sites, although the tendency to overhanging crowns may be a disadvantage; it is renowned for hedges. Growth may be slow until established and shelter helps. Under ideal conditions beech attains up to 33 ft in 20 years, 72 ft in 50 years and 100 ft in 100 years; on poorer sites growth usually averages 15 ft in the first 20 years and 40 ft in 50 years. Good quality beech is used extensively for furniture, poorer grades for general joinery.

The copper beech, var. *cuprea*, and purple var. *purpurea*, syn. *atropunicea*, are similar in requirements and growth to the type; other ornamental varieties, e.g. the fern-leaved var. *heterophylla*, are less vigorous.

Ash:

The common ash (*Fraxinus excelsior* L.) is an exacting species for good growth and timber, demanding fertile, moist soils, especially if calcareous and fairly deep. Shallower conditions satisfy if base-rich and ash tolerates most soils if high-quality timber is not expected. With its extensive root system it is a heavy feeder and thirsty but wind-resistant and standing exposure and smoke well if the ground suits. It is a strong light-demander, though more tolerant of shade when young. Frost-tender, it is preferably grown in mixture, confined to the interior of upland shelterbelts but more valuable on lowlands. Ash grows fast on good sites, probably averaging 2 ft for 10–15 years and 18 in. over 40 years. Its timber, the toughest and most elastic of British hardwoods, commands good prices and is valued for estate work.

The American ash (*F. americana* L.) is a possibility for similar but drier and sandy sites, where growth may surpass that of common ash. Heights up to 80 ft have been obtained in Britain. The manna or flowering ash (*F. ornus* L.) prospers on soils rather light for common ash but grows slowly to moderately. It is hardy and prized for its May flowers.

Maples:

Sycamore (*Acer pseudoplatanus* L.) is an important, dependable shelter tree, even for upland belts, preferring good deep fresh soils that suit ash but fairly adaptable to all but shallow and infertile sites if allowing deep rooting. It withstands severe exposure, even on sites open to the sea, although salt spray browns the foliage, and tolerates city conditions. Fairly frost-hardy and standing shade for the first few years, needing more light afterwards, it is best in mixture with other hardwoods and conifers. There is usually a steady demand for its timber for turnery and general household purposes. Growth on good sites falls below ash but reaches up to 18 ft in 10 years, 40 ft in 25 years, probably averaging 16 in. annually over 40 years. The

Corstorphine plane, var. *corstorphinense*, with yellow foliage turning to gold, is distinctly ornamental.

The Norway maple (*A. platanoides* L.) is a hardy species, similar in requirements to sycamore and liking deep fresh, base-rich soils and sandy loams but tolerating rather poorer and drier soils. It outstrips sycamore on good sites for 20–30 years, growth differences being more marked the more marginal the site for sycamore. Early height growth may amount to 2 ft annually for 15–20 years but 12–18 in. is more usual. It does not attain sycamore size nor life and trees over 75 ft are rare but is useful in mixtures, especially in the south and on ground barely suiting sycamore. Its autumn colouring has an ornamental value. It is intolerant of shade but withstands wind, smoke and seaside conditions.

The field maple (*A. campestre* L.) is a common hedge species, especially on calcareous ground in the south, rarely more than a small tree but occasionally attaining 70 ft. Dry stony soils in plains and valleys are ideal but it is an accommodating species, useful for edgings or ground cover in lowland shelterbelts, standing exposure and moderate shade, but not for colder upland or northerly districts.

The box elder (*A. negundo* L.) grows easily in town gardens, parks and on roadsides to form attractive, bushy-headed trees up to 30 ft high quickly. It is prominent in prairie windbreaks, perhaps scrubby in appearance but otherwise immune to wind and drifting soil. Several varieties are in cultivation. Of more ornamental maples, the American silver maple, *A. saccharinum* L., is a hardy, fairly wind-firm, town tree, tolerating smoke but needing open sunny positions and good moist loams to grow fast. The various varieties of *A. palmatum* and *A. japonicum* Thunb. are usually small trees or shrubs up to 20–30 ft high for the sunny, sheltered sides of garden and park windbreaks in southern districts, wherever amenity counts, but they are liable to frost injury.

Chestnut:

The sweet or Spanish chestnut (*Castanea sativa* Mill.) needs deep, fertile, non-alkaline soils, suiting clay and greensands in milder, moderately humid districts. It is unsuitable for chalky or exposed sites or northern districts, except as a sheltered understorey species in the latter. It is wind-firm, frost-tender and shade-bearing in early life. Its value in lowland shelterbelts is due to its readiness to coppice and maintain lower cover in narrow hardwood belts. Coppice shoots grow fast, often more than 2 ft per year for 15–20 years; as a timber tree, annual height increment is more likely to average about 15 in.

Elms:

The common English elm (*Ulmus procera* Salisb.), along with other field elms like the smooth-leaved *U. carpinifolia* Gled., syn. *U. nitens* Moench., and the more vigorous hybrids of *U.* × *hollandica* Mill., particularly the Huntingdon elm which may appear under the name of var. *vegeta* or *U. vegeta*, are typically hedgerow or park trees, the predominant species varying with locality. These find a use in narrow shelterbelts on deep, rich, moist soils, being frost-hardy but preferring mild conditions. They provide useful timber but are not particularly wind-firm and are likely to shed heavy branches without warning. They sucker strongly, thereby readily reproducing themselves, which can be a useful feature or a nuisance. On arable land their far-spreading roots and hunger are a disadvantage. They are fairly tolerant of town conditions, less so when young, also withstanding moderate shade and winds off the sea. Growth may average up to 12–14 in. per year for 20 years, perhaps rather more thereafter, giving lofty trees eventually.

The wych elm (*Ulmus glabra* Huds.) thrives under woodland conditions and extends into cooler regions than field elms, being typical of woods in Scottish lowlands and uplands on very rich, dry or moist soils of open texture. It stands more shade, demands less of soils and does not sucker; it is also more stable in wind than field elms, tolerant of sea winds and usefully incorporated in northern shelterbelts, especially near coasts. Its rate of growth is moderate. Like all elms, it coppices readily. It is also a useful underwood constituent or for margins where there is sufficient light for development.

Cornish (*U. stricta* Lindl., syn. *U. carpinifolia cornubiensis* and *U. nitens stricta*) and Jersey or Guernsey elms (*U. s.* var. *sarniensis* syn. *U. s. wheatleyi* and *U. c. sarniensis*) are handsome, pyramidal, narrow-crowned trees suited to lowland, fertile, sandy to heavy loams. Excellent for avenues, screens and roadsides, seaside situations and cities, they are also valuable for narrow farm windbreaks where overhanging crowns are to be avoided.

Hornbeam:

Hornbeam (*Carpinus betulus* L.), the 'white beech' of the Continent, is limited naturally to southern England but thrives elsewhere on well-drained, lowland sand or gravel soils and fertile calcareous sites and is very accommodating to stronger conditions, rich waterlogged ground and heavy clays. Withstanding wind, dense shade and frost hollows, and coppicing readily, it is particularly valuable for margin or underwood in shelterbelts, as well as for good hedges or screens for trimming or pleaching, even in towns if not too smoky. Growth is faster than that of beech, producing trees up to 70 ft high, but the tough, heavy timber may not find a good market. In mixtures hornbeam requires careful control.

Limes:

The small-leaved lime (*Tilia cordata* Mill.), the large-leaved lime (*T. platyphyllos* Scop.) and the hybrid, common lime (*T. europaea* L. Hayne) are all valuable shelter and screen trees. Deep moist soils are desirable but limes are adaptable to dry, shallow, base-rich soils and strong loams, *T. cordata* being least exacting if slowest in growth. They are frost-hardy, wind-firm, long-lived and tolerant of smoky urban conditions, common in streets and parks and gardens but summer infestations with aphids, fouling plants and pavements beneath, and early leaf-fall are disadvantages. All coppice or pleach readily and, being shade-tolerant to some extent, are useful for wind-firm cores or margins in lowland or upland shelterbelts. For single-row wind-breaks and screens they are renowned. Growth is fairly fast, averaging probably 18 in. annually for 15–20 years and 12 in. thereafter. The light, non-durable timber has limited value.

Horse Chestnut:

Horse chestnuts (*Aesculus hippocastanum* L.) are traditional park favourites but also valuable shelterbelt species in limited mixture, edgings or as an understorey in moderately light woodlands, thriving on very base-rich soils, both dry and moist, and deep soils overlying chalk and limestone, but tolerating shallow chalk, heavy marls and clays without the good progress that fertility produces. Warmer areas are most suitable. Horse chestnuts withstand fair shade and casts a heavy gloom, suppressing all below; it is wind-firm, good under most town conditions but somewhat frost-tender though able to recover. It is not long-lived, rarely topping 80 ft in height, but growth for 20–30 years may reach 18–22 in., rather less afterwards. The timber is of no commercial value. Several ornamental varieties are in cultivation, e.g. the red *A. carnea* Willd., some of them without fruit, an advantage in towns.

Walnuts:

For their high timber value *Juglans regia* L. and *J. nigra* L., the common and black walnuts respectively, may be fitted in singly or in small groups in a few shelterbelts on highly fertile, deep, moist soils that are not too cold, provided they are adequately protected by their neighbours. They are, however, frost-tender and not easily transplanted. Height growth may average 12–18 in. per year on suitable ground, top heights rarely exceeding 70 ft.

Alders:

The native common or black alder (*Alnus glutinosa* L.) occurs naturally along rivers and in fertile, low-lying fens but is extremely hardy and accommodating, often succeeding where other species with the exception of willows fail. It suits mainly the marshy and swampy sites, like alkaline East Anglian carrs, but not if badly aerated; very dry or infertile sites and acid peats should be avoided. It coppices well, bears a little shade and grows rapidly when young. Major uses for the species are on wet patches in lowland shelterbelts; as a quick-growing screen on difficult, wet sites; or as a pioneer or nurse for oak and spruce on heavy, wet ground. Its timber may be locally valuable for turnery or industrial uses. Town conditions are tolerated and there are several cultivated varieties.

The grey alder (*A. incana* L.) has similar requirements but replaces black alder on drier, base-rich soils, is ideal for loose, calcareous soils and on moist silty loams but dry, shallow and infertile conditions need to be avoided. It is not suited to heathlands and rough hill-grazings but moderately successful on some flush peats. On old arable land and derelict upland shelterbelts, it is a valuable pioneer, suckering freely and suppressing heavy grass to yield better conditions for other species. It is extremely hardy, somewhat resistant to browsing by stock and grows fast where there is adequate moisture and light, often averaging up to 2½ ft per year over 20 years. Trees are usually of moderate size but the timber is of no commercial importance. Grey alder also suits town conditions.

The cordate-leaved alder (*A. cordata* Desf.), though somewhat frost-tender, is more suited to drier chalk and limestone areas in the south, where it grows rapidly and tolerates a certain amount of shade. Acid sites are distinctly unfavourable. Again, it is mostly a pioneer species but could be retained in mixture or for the underwood.

Birches:

The indigenous birches, *Betula pendula* Roth. syn. *B. verrucosa* Ehrh., the warty or silver birch, and the common or white birch (*B. pubescens* Ehrh.) are very hardy and frost-resistant trees of the lighter, drier, acid sites, although adapted to various soils, even if poor and high-lying. Sandy and clay loams produce excellent growth. *B. pendula* is the more successful in drier climates and soils, whilst *B. pubescens* is the more tolerant of waterlogged and peaty conditions as well as moderate shade. They are wind-firm and ideal pioneer, soil improvers or nurses for frost-tender conifers particularly, although their whippy branches damage conifer leaders if not held in check. Sometimes they prove difficult to establish on new ground for trees. Withstanding city atmospheres, they have considerable ornamental appeal, growing fast when young but not long-lived and seldom reaching more than 60–70 ft. Markets for birch timber are very localized unless furniture or veneer sizes can be produced. The paper birch (*B. papyrifera* Marsh.) also grows fast and is a popular ornamental tree.

Willows:

Several members of this large, intricate family are useful for shelterbelts, narrow windbreaks and screens where suitably moist, fertile conditions prevail. The widely distributed, common white or Huntingdon willow (*Salix alba* L.) tolerates most lowland soils, frequenting streams and usually pollarded but otherwise a tall tree up to 90 ft in height. Growth is rapid, it is fairly frost-hardy and wind-firm, also tolerant of cities and situations near the sea, but the soft timber is of limited value.

The crack willow (*S. fragilis* L.) also forms large trees, reaching 70 ft if unpollarded and common in the Thames valley. It has a more spreading habit, the broad, rounded crown differing from the narrowish form and square top of *S. alba*, but is apt to suffer from strong winds. Many other species also produce osiers but *S. purpurea* L., a spreading bush up to 10–18 ft if not cut back, and *S. viminalis* L., a small tree up to 20–30 ft, are the most common.

The cricket-bat willow (*S. alba* var. *coerulea* Sin. syn. *S. coerulea* Smith) is the quickest grown and most valuable for timber, often putting on 3 ft or more per year in height and increasing rapidly in girth for marketing at about 16 years. Deep fertile sites with abundant, free-moving water and frost-free are essential for this.

Due to readiness to throw coppice or pollard shoots and quick growth, most willows can be used as single-row windbreaks or for shelterbelt margins giving protection to other species. But all require light and those to grow tall must have room to develop or will lean outwards from belt edges and overhang adjoining land. Coloured varieties have ornamental appeal, e.g. the golden willow (*S. alba* var. *vitellina*, syn. *S. vitellina*), which will grow to 60 ft but is usually pruned for winter effect, and *S. daphnoides* Vill., the purple willow, an erect vigorous tree reaching 40 ft if allowed freedom, but usually cut back.

Lastly, the sallow or goat willow (*S. caprea* L.), mostly a shrub up to 10 ft tall, is extremely hardy but also capable of succeeding at high elevations whatever the aspect and fairly adaptable to most soils, even when drainage is impeded. It is one of the few species which tolerate waterlogged peats and its chief value is for edging high elevation shelterbelts and as a pioneer or nurse, although perhaps needing control. The grey willow (*S. cinerea* L.) is the common sallow of the fens, similar in most respects but not confined to damp ground. The smaller *S. aurita* L., a small bush in upland siliceous soils, and *S. lanata* L., usually no more than 2–4 ft tall in the Grampians, may be mentioned also but are unlikely to be used unless wild plants can be lifted locally. All these are highly resistant to winds off the sea.

Poplars:

Poplars or cottonwoods are the most common shelter trees throughout North Temperate regions. The better varieties need deep, fertile soils well supplied with moisture and many are excellent for single-row windbreaks and screens set well away from buildings and drains. In a single line of poplars, ground shrubs may be necessary to maintain low cover, though with white poplars suckers may prove sufficient. These lines are difficult to replace without sacrificing all or part of the shelter but where there are 1, 2 or 3 rows, supported by more permanent species or a shade-enduring underwood, the poplars can be removed for profit at intervals, never more than 50 per cent at a time, and then replaced, a valuable aspect of shelterbelts if soils allow the good hybrids.

Of the white poplar group, the aspen (*Populus tremula* L.) is not exacting as regards climate, typically a frost-hardy tree of higher ground in the north than other poplars, tolerating various moist soils but not dry, stony ground, infertile sands or waterlogged conditions; best on silts where growth is rapid whereas it may remain small and bushy on heathland. It is strongly light-demanding and a useful nurse in upland shelterbelts, especially if some of the abundant suckers can be obtained locally. The grey poplar (*P. canescens* Smith), also hardy and highly wind-resistant, prefers moist fertile soils like low-lying silts but also fairly stiff, cold ground, occasionally reaching heights of 100 ft with graceful form. Sea winds and city atmospheres are readily tolerated. The white poplar itself (*P. alba* L.) likes slightly drier, warmer sites and is also hardy, wind-firm and resistant to seaside conditions. It grows moderately fast but varies considerably in growth and size with the situation. Possibly short-lived on exposed sites, it may reach up to 95 ft on fertile, non-alkaline soils. Both grey and white poplars sucker vigorously, useful for dense low shelter, and are good for windbreaks along field boundaries or for margins of, say, Norway spruce shelterbelts and as nurses but their timber is of little importance. They are also good town trees and an erect, columnar variety, *P. alba* var. *pyramidalis* Bunge, somewhat resembling Lombardy poplar, is common in parks and large gardens.

The black poplar (*P. nigra* L.) usually var. *betulifolia* Torr., is common on rich, wet soils of south and east England, recognized by its arched, heavy branches. Being extremely hardy and withstanding industrial pollution, it is often used as a trimmed or topped windbreak in market gardens and nurseries in such districts, frequently under the name of Manchester poplar. As a taller tree, bushy-topped and reaching over 120 ft, it has been superseded by more valuable hybrids. The vigorous Lombardy poplar (var. *italica* syn. *P. italica* Moench.) is widely employed in windbreaks and screens, often in situations where wide-reaching roots, on clay especially, have damaged building foundations. As a windbreak, the tight narrow crowns must almost touch for efficient wind abatement.

Black poplar hybrids are usually referred to by the collective name of *P. euramericana*, including the well-known *P. canadensis* var. *serotina* Rehd., syn. *P. serotina* Hartig, *P. robusta* Schneid., *P. regenerata* Henry, *P. eugenii* Simon-Louis and many others. These are the important volume producers, all vigorous growers, often 6 ft per year in height, given deep, fertile, moist, lowland sites but not generally in northern Britain where summers are cooler. Dry seasons and drouthy conditions can be fatal.

For less favourable temperatures and soils that tend to be slightly acid, the balsam group or hybrids between black and balsam poplars are more suitable but only canker-resistant strains are worth considering. Balsam poplars are also more adapted to semi-woodland conditions. *P. trichocarpa* Hooker, a valuable windbreak species, is the fastest growing, tallest of the balsams, especially in high-rainfall districts, reaching around 90 ft in height, but not all strains escape canker. *P. balsamifera* L. syn. *P. tacamahaca* grows more slowly but is now seldom planted, being replaced for a time by the hybrid *P. candicans* Ait., the Ontario poplar or Balm of Gilead, with a similar odour but highly susceptible to canker. A newer possibility is *P.* 'Androscoggin', a hybrid between *P. maximowiczii* Henry and *trichocarpa*, which grew 50 ft in 6 years on a good site. Amongst hybrids related to *P. berolinensis* Dippel., the popular *P. generosa* Henry often grows 6 ft per year but is not immune to canker and gales and eventually falls behind *P. trichocarpa*.

MINOR TREES AND SHRUBS—COMMON BROADLEAVED SPECIES

Certain smaller species are included above because they belong to the more important genera, e.g. mountain pine, sallow, etc. Those that follow are regarded as minor species, partly for size but more often because they are not timber trees. Most occur naturally in Britain; others have proved adaptable to field or woodland situations in different districts. For windbreaks where tall-growing species are unsuitable, many may become the principal shelter tree, e.g. whitebeam, sea buckthorn, etc. Other shade-bearing small trees and shrubs are properly of the underwood in shelterbelts. All are common species, which by no means exhaust the range of possible sheltering trees and shrubs, but no manageable volume could list the lot. Yet no locally successful species should be overlooked because it does not appear in the following notes.

Blackthorn (*Prunus spinosa* L.). Ranks second to hawthorn for stock-proof hedges and is a useful shrub for thick, low cover on exposed shelterbelt borders. Widely tolerant as regards soils and strongly resistant to wind and sea spray. Grows 3–10 ft high and soon spreads by suckering, so to be used cautiously in gardens. Particularly useful on very heavy clays.

Box (*Buxus sempervirens* L.). A slow-growing evergreen shrub or small tree of 10–20 ft. Tolerates most soils but most suited to light warm soils such as its native chalk and limestone areas in the south. Bears dense shade and has been commonly planted as an underwood on calcareous and sandy soils. It has similar uses in shelterbelts. Also common for low hedges and edgings.

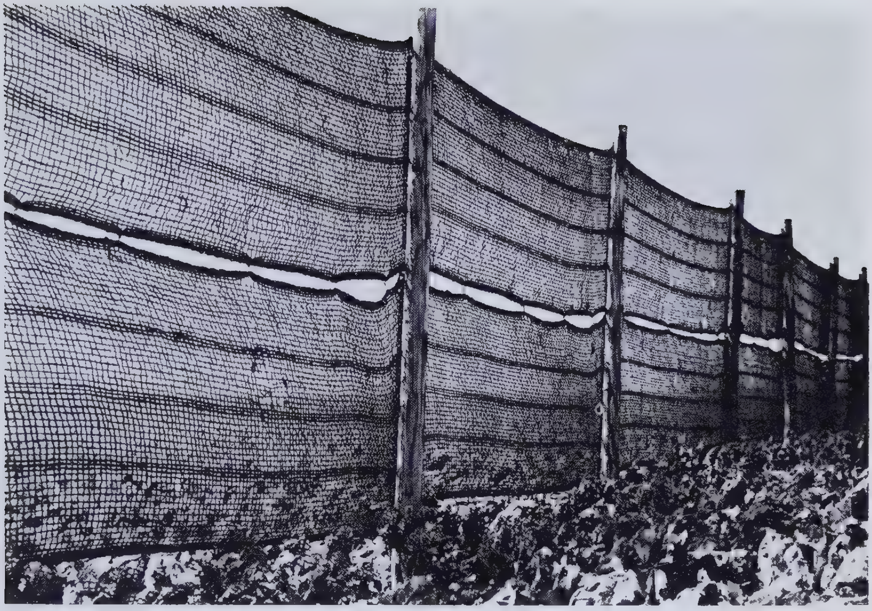
Broom (*Sarothamnus scoparius* L. Wimmer, syn. *Cytisus scoparius* Link.). A wasteland but decorative and useful shrub 4–10 ft tall. Planted for shelter as long ago as the 15th century. Most common on sandy soils in the east and on heathland. Widely tolerant of poorish soils, such as dry, light banks near the sea. Quick-growing, it can provide early shelter for young trees, particularly on unstable light soils, but may be difficult to eradicate. Also food for game. Cold upland winters are apt to kill it but it reappears after a time from seed. Tends to increase fire-risk in plantations. For town and garden use the cultivated *Cytisus* varieties with a wide colour range are better, easily grown and form excellent hedges or small windbreaks.

Buckthorn, Common (*Rhamnus catharticus* L.). Usually a vigorous shrub or small tree up to 20 ft high. Occurs occasionally in hedges and on woodland fringes on chalk formations in the south and east, tolerating very poor dry soils. Useful for windbreak margins where wild plants are available locally. Alder buckthorn (*R. frangula* L. syn. *Frangula alnus* Mill.), if obtained similarly, may be used as a pioneer on poor acid soils, old scrub woodland and with willows and alder on wet and boggy sites. A small bush occasionally reaching 15–20 ft. *R. alaternus* L. is a bushy, fast-growing evergreen, worth considering for exposed coastal gardens. Reaches 12–18 ft.

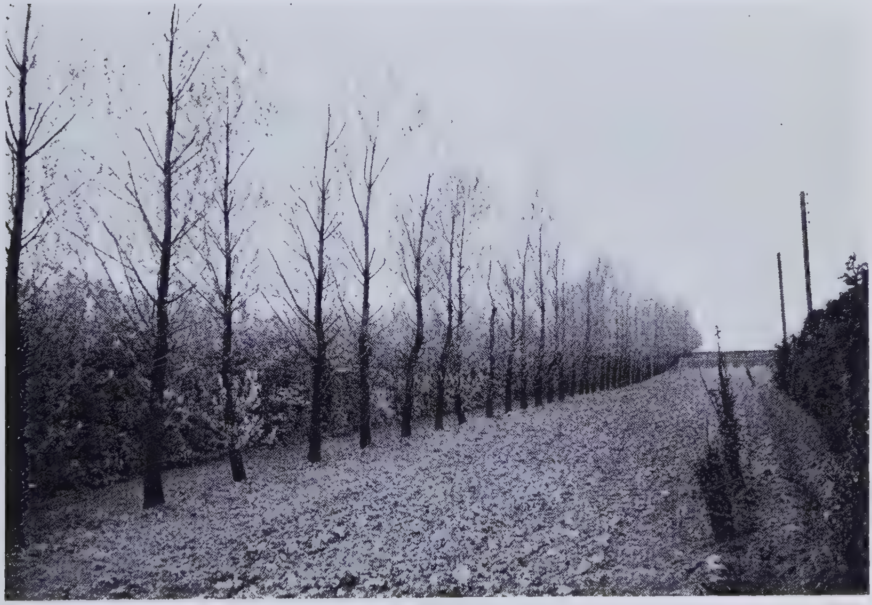
Buckthorn, Sea (*Hippophae rhamnoides* L.). Strongly light-demanding shrub or tree up to 20 ft high, flourishing on light coastal sands in parts of the east coast, where it is highly resistant to sea winds. In such situations a very hardy first choice for windbreaks, especially for land reclamation and to arrest drifting. Also a good outer protection for establishing shelterbelts of more valuable species on this gound but it dislikes competition. Although not long-lived, it regenerates itself readily by suckers on the edges of windbreaks where there is more light. Occasionally mixed with blackthorn. It will also succeed inland.

Bullace (*Prunus insititia* L.). Allied to blackthorn but usually larger, sometimes a small tree. Grows wild in the south and Midlands, often on woodland borders but not usually planted.

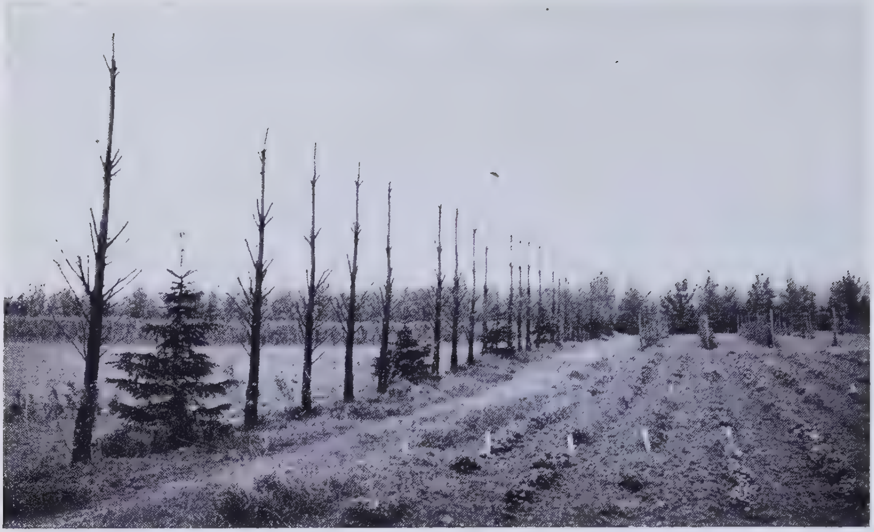
Cotoneaster (*Cotoneaster* spp.). *C. frigida* Wall., a good fast-growing semi-evergreen for town conditions, forms a beautiful small tree of 15–20 ft in height or a large shrub. *C. henryana* Rehd., a fast-growing evergreen of sparse habit is excellent for coastal planting. Both tolerate most soils. Various other species are renowned as hedges and covert shrubs, the best-known being *C. simonsii* Baker, which grows in most soils and situations to form a 7–8 ft formal hedge or, tolerating shade, a ground or game cover in shelterbelts.



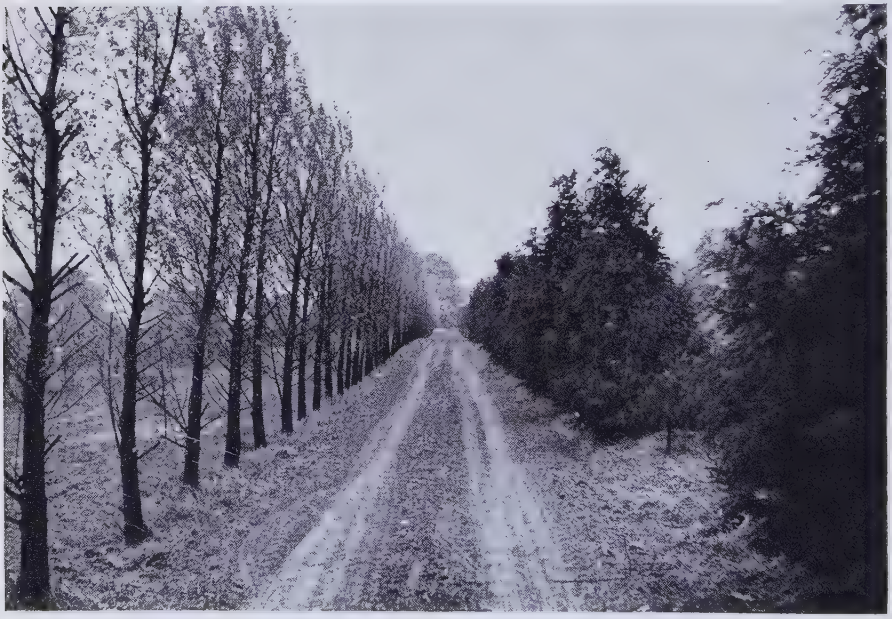
19 *Windbreak of coir netting in Germany*



20 *Black Italian poplars at 7 ft spacing, supplemented by beech hedge in the background and Lawson cypress hedge on the right*



21 *Windbreak of* Populus tacamahaca X trichocarpa *32, 10 ft apart, after hard pruning to check growth. Occasional Sitka spruce along the row*



22 *An effective all-the-year-round windbreak formed by an avenue of poplars and Leyland cypress*

Crab (*Malus* spp.). Wild crab (*M. sylvestris* Mill.) is a light-demanding woodland tree, especially on heavy soils, common in oakwoods and scrub but rarer in Scotland. Very hardy even if windswept in exposed situations. Usually a large bush or tree up to 20 ft high. *M. pumila* Mill., the downy crab, is the more common hedgerow species and one of the most attractive of wild flowering trees, extending to Morayshire on good soils and up to 30 ft tall. It has been the basis of some of the cultivated garden kinds, some of which deserve consideration for park and garden windbreaks. *M. floribunda*, the popular Japanese crab, withstands smoky conditions, flowers well but bears no fruit.

Cherry, Bird (*Prunus padus* L.). A highland species, occurring naturally as a bush or tree 20–30 ft high in Scotland, northern England and mid-Wales. Absent from south and east England. It suckers freely and is suited to clay and calcareous soils and even shallow peat on upland sites, where it can be used for the margins of coniferous shelterbelts up to high elevations.

Cherry, Rum (*Prunus serotina* Ehrh.). A prominent windbreak species in parts of Holland and Germany. Grows well on poorer sandy soils, reaching 30–50 ft high in Britain. A most useful species but for its position as alternate host for a virus-carrying aphid attacking sugar beet.

Cherry, Wild (*Prunus avium* L.). The gean may become a large tree over 70 ft in height in woodlands and elsewhere may reach 30–40 ft., growing moderately fast. Common on chalk downs in the south and thriving on most soils. Excellent for mixing with oak on very heavy, fertile soils or with beech in the Chilterns. A prominent species for woodland and shelterbelt margins, tolerating some shade but liking light. Hardy in most situations but not at high elevations or in colder areas or where soils are poor. Cherry wood is good for turnery and furniture but not usually grown for profit in Britain; in some German shelterbelts grown in mixture with alder for veneer markets. A popular ornamental in towns but in smaller gardens usually replaced by cultivated varieties of cherry and almond, many of which are also suitable for adding amenity to park and estate windbreaks.

Dogwood (*Cornus sanguinea* L.). A bush up to 12 ft high, preferring good calcareous soils, dry or damp, and old red sandstone areas. Most common on chalk downs as tough hedges or thickets on woodland edges and in scrub. On such sites it will maintain the underwood of windbreaks or make a good edging species with its coloured stems. Also valuable for game.

Elder (*Sambucus nigra* L.). Usually a bush up to 15 ft high but frequently a small tree up to 20–30 ft. Grows rapidly, especially on alkaline soils, dry chalk and sands. Common in gardens but often a weed there. Withstands considerable exposure, equally tolerant of city conditions and windswept coasts as far north as Shetland. Also an underwood species of light woodland. Unpalatable to livestock and readily obtained from seed or hardwood cuttings. Forms an untidy screen but valuable as nurse or wind-barrier for other species in difficult situations on lower ground. Exceptionally cheap if raised from cuttings or wild plants obtained but not to purchase because of its limited importance to nurserymen. The red-berried elder (*S. racemosa* L.), 8–12 ft tall, likes cool, moist conditions and is naturalized in a few districts of Scotland. Common on a few woodland fringes and can be used as *S. nigra* for windbreak borders. The golden elder (*S. nigra* var. *aurea*) is commonly cultivated and a useful shrub for low cover and decoration on margins.

Gorse, Furze or **Whin** (*Ulex europaeus* L.). A bush rarely over 6 ft tall, common on poorish but not infertile ground. Once commonly sown on Scottish sheep walks. Useful as a first barrier on exposed sites to protect new planting, particularly on sandy sites and banks near the sea, but it increases fire risk. Frost may cause winter injury from which it recovers. The lower, more compact species is often distinguished as *U. gallii* Planch., common on western siliceous grassland, often higher up than *U. europaeus*.

Guelder Rose (*Viburnum opulus* L.). An undershrub usually less than 12 ft high in moist oakwoods and alder woods on fen. Also found in hedges but requires moist, fertile soils and rare in Scotland. The snowball tree (var. *sterilis* DC.) is similar and commonly cultivated, also a possible species for ground cover or edgings in windbreaks.

Hawthorn (*Crataegus* spp.). Both the common hawthorn (*C. monogyna* Jacq.) and the less widely distributed Midland thorn (*C. oxyacanthoides* Thuill, syn. *C. oxyacantha* L.) excel as hedges and shelter, the former being better armed for stock fences. The Midland thorn prefers moist woodland on heavy clay or loam and stands more shade. Both grow to 30 ft if unchecked and withstand severe weather and industrial conditions, although leaning away from the prevailing wind in open, windy places. Widely tolerant of soils except at high elevations in northern Britain. Ideal for windbreaks but must not be allowed to become bare at the base with spreading crowns above, cattle often being the cause of this. Quick-growing, long-lived, hardy, cheap and responding rapidly to cutting or laying if necessary, they form excellent windward margins for shelterbelts, even in upland situations. Existing thorn hedges may provide a first line in new shelterbelts, a tremendous advantage to the establishment of young trees.

Hazel (*Corylus avellana* L.). Generally an underwood bush up to 10–15 ft high. Common in woodlands and southern hedges, tolerating most soils but preferring fertile, drier sites and chalk ground. Coppices readily, stands moderate shade and forms a soil-enriching cover under light-demanding species such as oak and pine. A good shrub for completing farm shelterbelts. The purple variety (var. *purpurea*) is equally vigorous and accommodating.

Holly (*Ilex aquifolium* L.). A good evergreen for windbreak borders or understorey, hedges and screens up to 30 ft high. Grows on most soils if not waterlogged but usually slowly. May reach 50 ft in good conditions. Withstands dense shade and most situations, including town or seaside, although heavy atmospheric pollution affects the foliage. Prefers mild, moist areas of the west. Various varieties are more ornamental.

Honeysuckle (*Lonicera* spp.). Certain bushy honeysuckles, e.g. *L. tatarica* L., are frequently employed for the edges of American windbreaks. This species is well-adapted to garden conditions in Britain, usually vigorous and growing to 8–10 ft. It could be used with appreciable effect for bordering garden and park windbreaks here. *L. nitida* Wilson is a popular hedge species, growing up to 5 ft, but not as hardy as privet or so robust. Severe winters may be fatal and there is a tendency to die out at the base. Easy to propagate from cuttings, it is good for the underwood and for game beneath light-crowned species.

Laburnum (*Laburnum anagyroides* Medik.). A small tree up to 20 ft high for town, country and seaside. Occurs in hedgerows in Pembrokeshire and a few other areas but more common in gardens. Widely tolerant as regards soils and a vigorous grower when young. Not recommended for farm shelterbelts as the foliage is poisonous to stock, particularly when withered. An excellent, hardy ornamental for the edges of windbreaks in park and garden or as a screen by itself. *L. alpinum* Presl., the Scotch laburnum, is usually preferred for gardens.

Laurel (*Prunus* spp.). Cherry laurel (*P. laurocerasus* L.) and Portuguese laurel (*P. lusitanica* L.) readily form dense, low cover on shelterbelt margins, even when heavily shaded. Portuguese laurel is the more hardy and more widely tolerant of soil conditions. Both are suitable for game coverts and formal or informal hedges, also making a strong windbreak up to 20 ft or so in height.

Lilac (*Syringa vulgaris* L.). A familiar bush or small tree up to 20 ft high, forming attractive informal hedges or screens, especially on fertile, base-rich soils. There are many cultivated varieties, all heavy feeders and responding to manuring. Easily grown on garden and farm shelterbelt margins for lower cover and effect but liable to be mutilated when in flower in some parks. A good rootstock is important as well as adequate light.

Myrobalan (*Prunus cerasifera* Ehrh.). Also called cherry plum. A large bush or small tree up to 25 ft high. A standard hedging plant, adapted to most soils and situations. Withstands reasonable exposure, appreciable shade, hard cutting and laying. Useful for low windbreaks, shelterbelt margins or understorey in lighter stands. The copper-coloured var. *atropurpuera* syn. *pissardii*, a specimen tree but also used in hedges for variety, and *atropurpurea nigra*, even darker, make useful wind-screens up to 20 ft in height. The wild plum (*P. domestica* L.), not so easy to purchase, is also good for shrub margins in windbreaks.

Pear, Wild (*Pyrus communis* L.). More pyramidal in habit than the bushy crab. Grows 20 ft or more high and wild in some southern counties but not commonly planted. Useful on margins if available. The weeping var. *salicifolia* Pallas., more a Victorian favourite than latterly, is a good, hardy ornamental, liking somewhat alkaline loams.

Privet (*Ligustrum vulgare* L.). A semi-evergreen shrub up to 10 ft tall. Prefers calcareous soils in the south but grows on most. Can be used on windswept sites in town and country or near the sea Shade-tolerant and suitable for low cover in lowland shelterbelts or to close gaps on the borders. The Japanese, oval-leaved privet (*L. ovalifolium* Hass.) is slightly larger, reaching 12–15 ft if free-growing, more common for hedges and usually cheaper. Coloured varieties are available.

Rhododendron (*Rhododendron ponticum* L.). Grows prolifically on acid areas of wet, western districts, including peats. More ornamental varieties are widely cultivated. In large gardens and parks as a windbreak or informal hedge it is admirable. Tolerant of most soils except chalk; town conditions also suit. Useful for maintaining an understorey in shelterbelts if occurring locally but to be used with caution in situations ideal for the species since it can complicate restocking of the overwood and is expensive to eradicate. Poisonous to cattle although rarely eaten by them.

Roses (*Rosa* spp.). Several wild roses are excellent, hardy edging material for windbreaks for most purposes, especially if abundant locally. Dog-rose (*R. canina* L.) is a vigorous shrub 3–10 ft high with arched, erect shoots. Scotch-rose (*R. spinosissima* L.) is lower, up to 3 ft, but grows on poor, dry and sandy soils, notably coastal sands. The extremely hardy *R. rugosa* L. has similar qualities but reaches 3–5 ft, even on lime-rich clays and the poorest sands; highly resistant to wind and much used for forest fringes and ground cover on sandy heathland in

Jutland. The sweet briar (*R. eglanteria* L., syn *R. rubiginosa* L.), common for hedges, resembles dog-rose but has stiffer, more upright form, up to 6 ft tall.

Rowan or **Mountain Ash** (*Sorbus aucuparia* L.). Hardiest of all British trees and one of the most valuable for shelter purposes. Succeeds at very high elevations on all aspects and in open woodland and scrub over most of the country. Attains heights up to 40 ft. Characteristic of moister uplands and siliceous soils of the west and north, extending to the tree limit. Also found on sandy and light, dry, acid soils, even peats, but avoids clays and soft limestone. Highly wind-resistant; ideal for shelterbelt margins at all elevations or as a pioneer and nurse on most infertile soils and heaths. Various ornamentals are easily cultivated for autumn tints or coloured fruits, thriving almost anywhere and growing moderately fast, e.g. *S. americana*, *S. commixta*, *S. discolor* and others.

Service, Wild (*Sorbus torminalis* Crantz). Comparatively local in occurrence, on clay and sometimes limestone in southern counties. Usually a thick bushy shrub up to 30 ft tall. *S. domestica* L. is the true service tree of gardens, a possible inclusion in windbreak margins.

Snowberry (*Symphoricarpos albus* Blake). A low shrub 3–5 ft high, standing dense shade and providing low cover in shelterbelts whilst maintaining good soil conditions. Easy to cut when further planting demands but difficult to eradicate. Particularly useful for the underwood of snow-collecting windbreaks on most dry and moist soils.

Snowy Mespilus (*Amelanchier spicata* Koch.). A slow-growing shrub 6–12 ft high, widely tolerant and hardy, sometimes forming thickets of sucker shoots on forest margins, where useful for amenity. Included in outer rows of some windbreaks.

Spindle-tree (*Euonymus europaeus* L.). Usually a bush up to 15 ft tall; occasionally a small tree to 20–25 ft. Common on chalk, limestone and base-rich soils but unusual elsewhere. Forms a good hedge or low screen but not for arable areas since it overwinters the bean aphis. *E. japonicus* Thunb. has been widely used in coastal and smoky towns for evergreen hedges up to 12 ft and in such areas can be a useful constituent of windbreaks.

Spiraea, Willow-Leaved (*Spiraea salicifolia* L.). A suckering shrub, 3–6 ft tall, growing on acid soils in North Wales particularly. Withstands considerable exposure. A good margin species in this area and on other damp ground.

Tamarisks (*Tamarix* spp.). *T. gallica* L. and *T. anglica* Webb are evergreen shrubs up to 15–20 ft, frequently used for windbreaks in mild, windswept coastal situations. Resist salt spray and can be cut to promote a bushy habit, otherwise stems become bare at the base. Strongly light-demanding, best in sunny exposures. Thrive in sheltered spots inland and on most soils if not shallow and chalky. *T. pentrandra* and *T. tetrandra* Pallas. are similar; the last is most common in gardens.

Tea-tree (*Lycium chinense* Mill.). A vigorous bush up to 10 ft tall, widely tolerant, wind-firm and highly resistant to salt spray. Extremely useful for hedges, low screens or as a first line of defence on sandy ground close to the sea. Often spreads by suckering. *L. halimifolium* Mill. is similar but sometimes less vigorous. An allied species is common for stock fences and farm shelter in New Zealand.

Wayfaring Tree (*Viburnum lantana* L.). A shrub or small tree up to 20 ft high, replacing guelder rose on chalk sites in the south-east, for which it is most suited. Tolerant of dry or moist conditions.

Whitebeam (*Sorbus* spp.). *S. aria* Crantz is typical of calcareous soils in the south but occurs elsewhere. Replaces rowan on pure chalk and limestone, often occurring in hedges. Different types, sometimes species, are recognized, e.g. Cornish whitebeam; the upland variety in Wales and Scotland; the presumed hybrid on Arran. Very wind-firm, withstanding exposure to sea winds, and an excellent tree of up to 50 ft in height for edging shelterbelts or as a pioneer or nurse on windy, chalk ground. Sometimes seeds naturally along woodland margins, e.g. in central Wales. Swedish whitebeam (*S. intermedia* Pers.) is much used for shelter in Scandinavia and has proved successful in Britain, growing faster than *S. aria* and attaining heights up to 60 ft. It displays remarkable resistance to exposure, city smoke and industrial conditions and is also tolerant of peaty soils and *Calluna* heathland. Good for single-row windbreaks also, withstanding trimming.

7 Designing Small Windbreaks

WINDBREAKS FOR HOUSE AND GARDEN

Normal winds possess a prevailing horizontal component that flows more or less parallel to the ground. In addition, turbulence provides rising and falling components which give the gusts and lulls; these may become dominant when the wind is disturbed. For this reason, large obstacles nearby may modify the effectiveness of a windbreak. Down-draughts caused by a neighbour's roof, for example, may ignore completely the screen or wall that would otherwise shelter the garden on that side. Such added problems must be taken into account when planning wind protection for house and garden.

Furthermore, some compromise may be necessary between what is best for the house and what is best for the garden. One or two tall, heavily-crowned trees in the corner of a property may absorb most of the buffeting of the wind and reduce the pressure and suction loads that lift tiles from a roof in a gale. Under more normal conditions and especially when in leaf they may deflect currents round and under the crowns and present a nuisance in the garden. On the other hand, a garden surrounded by a good hedge or wall may be effectively sheltered whilst the house rears its head well up into the wind. Unless the area allows a narrow windbreak to grow tall and protect both without blocking out the sunshine, a choice must be made to suit the circumstances.

Built-up areas have to contend with limited space, the funnelling and eddyings caused by surrounding buildings and the general draughtiness of towns. In contrast, a house in open country or set in spacious surroundings is spared these complications, even though stronger winds may be anticipated. In many cases sites will have been chosen to take advantage of natural shelter afforded by topography. Even when this is not the case there may be a better chance of making use of existing features, particularly single trees or clumps, which may be used as the basis for a shelter arrangement, suitably supplemented by fresh planting.

In all cases, a first step should be to seal off any obvious wind funnels. For draughty, narrow gaps, such as between the wall of a house and garden fence in the typical residential area, trellis

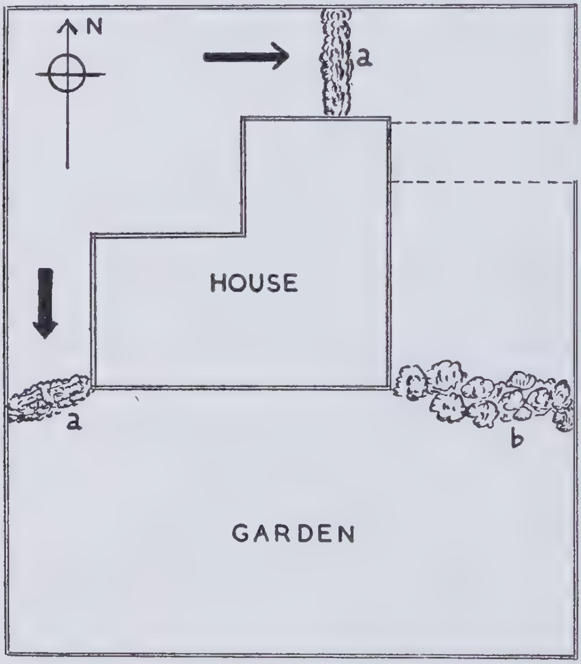


Fig. 16 *Obvious wind funnels, as at (a), should be sealed off. Checking cold northerly winds, (b), enhances a southerly aspect.*

type fencing provides the quickest answer and is easily reinforced by shrubs on one or both sides for effect and also for greater stability under gale-force winds. For wider channels for the wind, formed perhaps by the lie of the land or by the disposition of outbuildings, there are other possibilities. But these funnels are often the source of trouble and provoke a need for shelter; draughts and sudden accelerations of the wind are to be feared far more in a garden than the free, undisturbed stream.

It is also important to decide where shelter is most required and when. The prevailing wind, which may not prevail as much as half the time in any case, may not be unduly troublesome. Unpleasant winds during the colder months may be more in need of tempering. To lessen the force of winter gales and to improve indoor comfort, clumps or lines of tallish trees in the right quarter are essential. The worst winds come from the north-west, north and north-east and windbreaks on these sides can approach nearest the house they are intended to shelter. The taller the trees the farther away they should be. Few people naturally want to decide this distance on the basis of the height the trees will attain in, say, eighty years and there is no need for this, provided it is appreciated that tall, timber trees too near houses and boundaries can present a serious and expensive problem. This can be avoided by selecting trees that are unlikely to reach large proportions or can otherwise be topped or removed and replaced once they reach the maximum height permissible. There is an unfortunate tendency to retain trees long after they have outgrown their usefulness and many Victorian residential areas are now marred by old elms, beeches and ash trees too bulky for their surroundings. This criticism usually applies to specimen trees, which should have been replaced by something smaller but equally attractive and useful long before they became a menace, but it is a point to be observed when designing garden windbreaks.

On the north side of a house, a windbreak can be as near as 60 ft, depending on the type of tree employed, but it is better to keep this distance no less than 2½, and no more than 5, times the ultimate height of the barrier. Those that shelter North

American houses are usually 100 ft at least away. It would be reasonable to plant tall-growing trees at this distance, bearing in mind that by the time they have reached 50 ft in height, probably in less than 30 years, they are going to be too near for good shelter. Yet, until they have grown to 20 ft, they are too far away. Anyone planting trees for shelter is advised to take a long-term view of his actions, although it is natural to want wind protection as early as possible. But it is equally important for later generations to remove any trees that are becoming too tall for their location, rather than to accept the situation until a major problem is presented.

A north-side windbreak can be continued with advantage round the north-east and north-west corners, but probably turned or curved towards the south-east and south-west respectively if space permits. This arrangement promises valuable shelter at the coldest times of the year. Windbreaks down the east and west sides of a house, however, interrupt a good deal of light if too near to it. Some loss of light must be expected if the distance is nearer than 6 times the height of the barrier, although as stated above the best shelter is between 2½ and 5 'heights' downwind. Maximum illumination is less important for a house than for a greenhouse but the limited winter sunshine is not readily spared. Therefore, it is preferable to site shelterbelts on the east and west of a house at 4 or 5 times their height away, which means losing a little light in early morning or late afternoon, respectively, but not from May to July when the sun is highest.

Most house-owners require free exposure to the south but if shelter is required between south-east and south-west there must be some compromise between wind protection and sunshine and, perhaps, the view as well. However, windbreaks at a distance of 4 times their height cause little direct shading or loss of light and this is greatest at the beginning and end of a midwinter's day. For a windbreak orientated from north-west to south-east to halt a prevailing south-westerly wind this should be increased to 5 'heights', i.e. 50 yds. for a 30-ft screen.

Except for a few country manors where a walled garden may be set apart from lawns and shrubberies that provide a setting for the house, the disposition of windbreaks to protect a residence must also reckon with their advisability from the point of view of the garden. The more limited the space the more important shade and root robbery become.

For south-facing houses with not less than 50 ft of garden at the back, preferably more, tree screens of suitable height, i.e. 20 ft and upwards, shelter both house and garden against the coldest quarters and, in addition, provide a warm, southerly aspect in their lee for sun-loving plants. No shading arises in the garden but it must be remembered that a neighbour's garden may be affected on the other side. Because south-facing borders are the most valuable part of a garden, trees which interfere greatly with cropping are not wanted. If a wall other

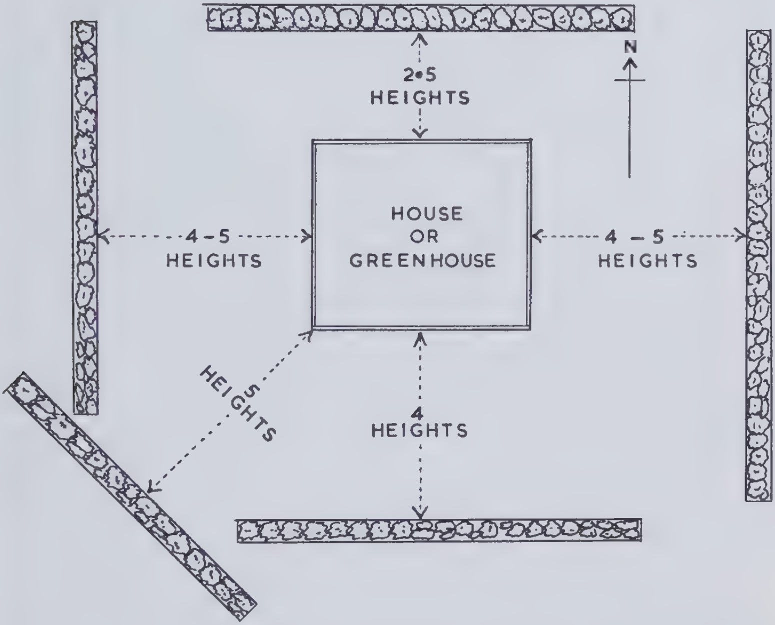


Fig. 17 *Minimum distances between a house or greenhouse and windbreaks in order to combine satisfactory shelter with least loss of light.*

than a boundary one stands at this end of the garden, a tall windbreak planted on the outside if possible can produce conditions ideal for tender fruits like nectarines and peaches. Set back from the wall, at least 4 ft if side-pruned, or 8 to 12 ft according to spread of crowns, to avoid overhanging branches, a windbreak intensifies the warming-up of the sheltered plot, creating almost greenhouse conditions outdoors. The warmest conditions on this side are obtained from a wall or windbreak turned to face the sun at about 2 p.m., giving an aspect displaced slightly towards the south-west.

With less than 50 ft between house and garden wall on the north windbreaks to grow beyond 20 ft high should not be attempted. Small trees mixed with shrubs, pleached screens and free-growing or formal hedges are most suitable. Pleached screens for the small garden can look well if carefully trained and are popular on the Continent; poorly pruned they can be hideous in winter. Whatever the choice, height growth should be restrained to about two-fifths the extent of the garden, i.e. 16 ft where the length of the garden is 40 ft. Inevitably, this limits the wind protection that can be provided for the house, at least for upper storeys, but it is usually the downstairs regions that are most in need of measures to conserve heat and even a 6 ft hedge makes some difference here.

Houses that face south and have most of the garden to the front often lose the full benefit of this warm sunny position due to cold, north winds that eddy round the corners. Clumps of trees, lines of shrubs or artificial screens at the side of a house prevent this, the arrangement depending on the area available. Where there is space to spare, windbreaks that curve outwards towards the south-west and south-east can deflect the wind stream away from the front garden and allow full advantage to be taken of sunshine.

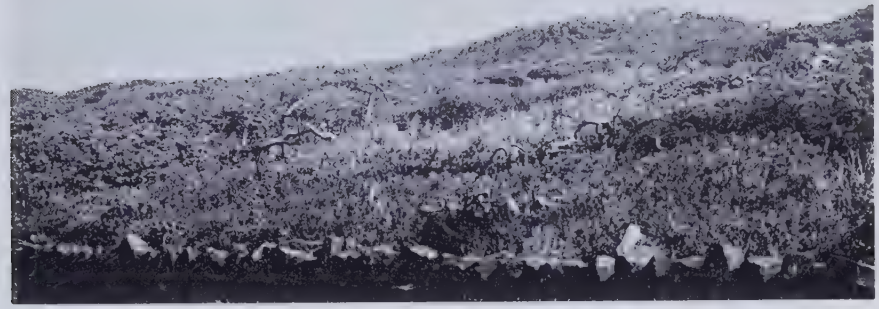
For adequate shelter near the ground and an improved environment in gardens, windbreaks on the west and east sides of a garden need be no more than a tenth of the garden width in height. Shelters for gardens 100 ft across should not as a rule be more than 10 ft high, although up to 14 ft might be permissible in certain cases, i.e. one-seventh of the width. Taller windbreaks cast more shade and may cause the enclosed air to stagnate without materially increasing the degree of shelter for garden crops. However, as explained earlier, they may be necessary for sheltering a house. An orchard can sometimes be used to shelter a garden but unless there are several rows of fruit trees, and more for standards than for half-standards with their lower crowns, something more may be needed to break up the wind that sweeps underneath the trees. Orchards on the leeward side of shelterbelts are probably more useful by overcoming the problem of cultivating the strip adjacent to the trees, especially if a species with far-reaching roots is employed. At the same time they extend the windbreak effectively without altering the total permeability to any marked degree.

For the most part, gardeners are content with shelter in the form of a conventional hedge or a narrow tree screen that can be pruned, pleached or topped at a convenient height. Hedges, like formal and informal arrangements of shrubs, secure wind protection whilst also serving as backcloths to borders. In addition, mixing sensitive and hardy plants or using climbers and tall plants to protect the small and tender provides for a good deal of local shelter where nothing more is available. Whatever method is employed, the most serious danger arising from too much shelter is an increase in the likelihood of frost. Guaranteeing protection for house and garden from cold, ravaging or drying winds is one thing; preventing ventilation and thereby favouring fungal diseases in the humid days of summer or, more important, because remedial action is less straightforward, increasing the risk of radiation frost is another. A fall of temperature below freezing point, even for a short time during the coldest part of a spring night when air movement is in any case at its lowest, can be severely damaging. Garden windbreaks, therefore, need to maintain what little air circulation there is when nocturnal cooling is strong. Otherwise, frosts set in earlier in the sheltered area, and, consequently, more severely on nights when frost is inevitable; frosts may be produced on other spring nights when temperatures elsewhere stay just above the zero mark. Belts need to be sufficiently open to allow even the lightest breeze to penetrate. This applies particularly to screens at the foot of sloping gardens, from which cold air must be allowed to drain away. Permeable windbreaks are better than solid walls for such situations. On the other hand, windbreaks at the top of sloping sites can be dense at the bottom to check the river of cold air from entering the garden.

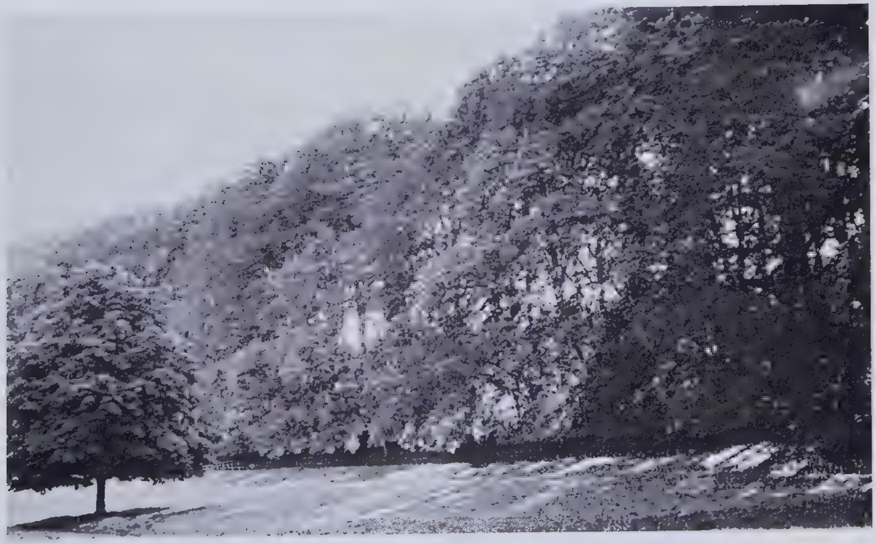
On level ground frost risk always rules out the dense windbreak. Most narrow belts are rarely impenetrable in the sense of a stone wall but a very thick mass of foliage can build up still pockets of air behind and become a potential hazard. Pruning or thinning is a certain remedy for this. When the air is absolutely calm other means of frost control must be considered, since windbreaks cannot accentuate or alleviate the situation.

If frosts are frequent, windbreaks composed of deciduous trees, which are not dense when the worst frosts occur, have obvious advantages provided they are suitable in other respects. Deciduous shelterbelts, if well-branched, afford appreciable wind protection in their leafless state and their effectiveness in controlling winter winds can be increased by including a few evergreens, but not in a continuous line, in frosty localities. Similarly, late-flushing species like oak, ash and some elms, can be useful against frosts in May. The aim must be to obtain the minimum wind velocity, i.e. the maximum shelter, a little behind and not immediately at the windbreak. This can only be found by practical observation but it is worth checking on an average windy day rather than to suffer the calamity of a spring frost needlessly. A few hours' pruning or the removal of the occasional tree can make a dense windbreak more permeable to wind and reduce frost risk; if not overdone this will also improve the quality of the shelter.

Bearing in mind the tendency for dense structures to incur a greater danger of frost damage, the composition of windbreaks should be decided according to their seasonal state when shelter is most urgent. For the best performance against cold, winter winds an emphasis on evergreen species is desirable. This would apply particularly to belts on the north-west and north-east of



23 *Wind-shorn tree crowns in a coastal shelterbelt*



24 *Beech and ash on a chalk bank on the Lincolnshire Wolds providing a sheltered corner against west winds*

25 *Tall, well-spaced trees interplanted with shade-tolerant shrubs and an edging of* Aucuba japonica *to afford a sheltered corner in a public garden*

26 *Small beech clump on a knoll reinforced by a few conifers for extra effect and better shelter*

a property. Too high a proportion of deciduous species in the structure would allow too much wind through in the winter unless thickly planted, in which case there would almost certainly be turbulence and down-draughts when in leaf and these are wanted least of all in the summer. Conifers, on the other hand, vary little in density throughout the year, and provide shelter at much the same rate in summer and winter. Where summer shelter is of primary importance, a windbreak should be most efficient at this period, i.e. not more than moderately dense when in full leaf. Such a windbreak can be entirely coniferous or deciduous in character, given the appropriate spacing, but, where broadleaved species are used and especially in mixture with conifers, attention should be given to species lightly clothed with foliage, e.g. aspen, white poplar, birch, false acacia, laburnum, hawthorn, willow and many varieties of *Sorbus* and *Prunus*. Proportions of evergreens can be increased where there is a need for more shelter in the spring before deciduous trees come into leaf. It must be remembered, however, that a cold, heavy soil may respond to extra ventilation at this time.

For small windbreaks around dwellings a mixed composition gives a better appearance than do pure structures and, except in a single row, makes future control easier.

Artificial Windbreaks

The simplest windbreaks for limited spaces are formed from trellis-type fences sufficient to check the wind but not obstruct it too abruptly. Various designs in a range of sizes are now marketed. Most afford good shelter but, where more than 40 per cent permeable, i.e. when more than two-fifths of the superficial area when erected consists of openings and gaps in the weave, efficiency can be increased by training climbers over the fence. Frames of strong wire netting, sold as pea and bean trainers, wattle hurdles, etc., afford similar opportunities. Any kind of paling or board fence will make a windbreak but solid structures need to be avoided on two counts: firstly, they do not provide the best shelter; secondly, they have to withstand high wind pressures if they block the wind completely. An improvement on the usual impenetrable wooden fence is one with the top foot or so of open lattice; the latter breaks up most of the eddies rolling over the fence.

All such screens need to be braced against strong winds and, if expected to last more than five years, to be made of durable material or treated with suitable preservatives. Open or rough types of fencing can easily serve for shelter if reinforced and disguised by a suitable climber. The accommodating Russian vine, *Polygonum baldschuanicum*, is a simple example; more desirable species generally take longer to form a good screen. Rambler roses, trained on rustic larch fences or pergolas, can provide useful shelter within two years. Again, arranged in a series of fan shapes against horizontal wires nailed to stout posts, they occupy the minimum of space. Blackberries are used in this fashion by some commercial growers. Roses and blackberries, however, require a good deal of pruning and there are other shrubs which can be trained against the sides of a windscreen whilst needing less attention.

Small artificial windbreaks, whether supplemented by climbers or not, make the most of the sunshine and can greatly enhance the pleasure derived from a garden. Being cheap and easily moved, they allow the maximum flexibility and avoid changing an existing garden layout.

Formal and Informal Hedges

Good, well-trimmed hedges, informal rows of shrubs or a mass of shrubbery all afford useful, low shelter. The subject of hedges is dealt with extensively in gardening literature but a few points warrant repetition.

Hedges formed from single lines of plants are generally preferable to those composed of two rows and allow better development of the individual plant. In most cases plants two feet or less in height should be used; smallish plants allow a better chance of good root development and are invariably cheaper to purchase. Distances between plants vary according to size and habit: small plants of *Lonicera nitida*, privet and thornquicks (less than 12–18 in.) can be 9 in. apart, whilst 12 in. is better for most deciduous species like beech, barberry, blackthorn, *Cotoneaster*, elm, hawthorn, hazel, hornbeam, field maple and myrobalan. Bushier species such as broom, elder, *Escallonia*, holly, laurel, tamarisk, Lawson and Monterey cypresses, *Thuja* and yew should go 18 to 24 in. apart. Very spreading species like hydrangea, *Philadelphus* and rhododendron are best at 30 in. apart.

Most deciduous species can be planted from mid-October until April, evergreens either in late September or October or between March and early May but the weather and soil conditions must decide. Planting in cold, wet and sticky soils during winter months is not advisable and seriously hampers rooting, often fatally. Ground usually needs thorough cultivation before planting; double-digging ensures maximum success whilst a deep trench taken out allows any sods to be turned over in the bottom.

The hedge should then be firmly planted, and well-watered in a dry spell, to enable roots to establish contact with the soil. Surface cultivation should continue for the first year or two to keep down weeds. It is often more important to eliminate competition from weeds and other crops nearer than three feet to the hedge than to rely on expensive preparations such as deep cultivation and heavy applications of manure and fertilizers. Mulching also controls weeds, at the same time conserving moisture, and a mulch of well-rotted stable manure will also boost a poor, infertile soil. An early summer top-dressing of sulphate of ammonia, nitrate or potash also has this last effect should the need be apparent.

Whether a formal hedge with vertical sides or, preferably, tapering towards the top to give low branches more light if the species is strongly light-demanding (never wider at the top than the bottom), it is important to restrain height growth so that the hedge remains thick at the base. The more reluctant the plants to adopt a bushy habit, the harder this pruning of leading shoots should be and should certainly not be postponed. Informal hedges require less attention and a light pruning suffices to maintain the general form and mixture. Those intended to flower must be treated according to the usual rules: for flowers on new growth, prune in winter or early spring; if the flowers appear on the previous year's wood, prune after flowering; if on spurs and side shoots, prune as little as possible.

Shrubberies:

A massed array of shrubs can serve as a windbreak and the wider the strip the more important it is to allow some wind to filter through or between the shrubs. Once such a barrier becomes wind-proof its shelter value diminishes. Mixing shrubs of varying heights avoids this danger; occasional trees dispersed amongst the shrubs give extra height but there must be no through-gap between the bottom of their crowns and the tops of the shrubs. These arrangements are particularly useful for bordering drives or dividing a garden, provided of course that this direction lies across the wind.

Pleached Screens

Pleached screens of limes are occasionally used to surmount a wall at the end of a garden, appearing in summer like a hedge supported on regularly spaced stems. They are efficient, occupying little space in relation to their effective height, and sieve the wind deflected over the solid wall or fence which keeps the bottom part of the barrier closed. Trees 5–6 ft tall are planted 6–10 ft apart and not pruned until well established, usually when 8–12 ft high. They are then topped, front and back branches removed and other side branches suitable for training into the screen slightly shortened to promote branching. Branches of adjacent trees should not be touching, thus allowing new, young shoots to complete the screen in the spring. Annual pruning is, of course, necessary and for screens which may be 15 ft high this can be laborious or expensive without mechanical equipment.

Beech, hornbeam, chestnut and plane have also been used in the once popular pleached 'alleys'. Fan and horizontal-trained fruit trees, especially apples and pears, lend themselves readily to such arrangements and are worth serious consideration where space is limited and screens up to 5 ft or so in height are required. Some means of support may be necessary for the first few years, after which stems are stout enough to withstand the wind. Pruned for fruiting, shelter during winter months is almost negligible but usually adequate during the summer.

Single-row Tree Windbreaks

Hedges are commonly limited as regards height and something taller is often required. Yet, whereas the qualities of hedges are readily turned to account, there is generally greater reluctance to attempt windbreaks composed of a single line of free-growing trees or a mixture of trees and shrubs. This need not be the case. One-row windbreaks dampen winds and provide ample shelter wherever soils and exposure allow trees to reach a suitable size. Most garden conditions meet these requirements, although coastal and upland situations exposed to stronger winds and probably invested with poorer soils and less rewarding growing conditions need more rows to offer better prospects of success. The more exacting the overall environmental conditions of soil and climate the more necessary it is to use the hardier species in addition. Such sites are fewer than the windswept face of certain districts suggests and improvement of soil conditions, physically through cultivation and chemically through manuring, greatly alleviates problems of exposure. For most houses and gardens, single-row windbreaks occupying little space and 15 ft upwards in height are a practical possibility and are not restricted to sombre lines of cypresses, overpowering poplars or outgrown hedges.

In planning such windbreaks there are two major alternatives: firstly, to select a reliable species certain of forming an efficient screen, even if more functional than decorative; secondly, to cater for aesthetic appeal initially, inevitably placing more practical qualities secondary. Where the need for shelter is urgent, the first is the obvious course; specimen trees and shrubs to add colour and interest can be added to the foreground once the barrier itself is established. However, some of the cypress tribe, for example, retaining branches to the ground, are effective whilst neither dull nor slow. The second entails more risk since it is never easy to mix species of different form and habit within a single row and at the same time create an efficient wind barrier. Some species are more difficult to establish than others, especially ornamental varieties, and tend to delay the formation of a sound windbreak. Intricate mixtures are more appropriate for multiple-row belts.

Height must be a major consideration and the fastest growers are not usually the most permanent nor the most desirable. A species amenable to topping without detracting from appearance has an advantage if there is any danger of its outgrowing its surroundings or requirements. In this case few species can compare with the accommodating Lawson cypress or quicker *Thuja* or, for mild situations, *Cupressus macrocarpa*. More expensive but usually worth the price, the hybrid *Cupressocyparis leylandii* is one of the fastest-growing conifers in Britain, making a superb hedge or tree screen in comparatively short time. It is not advisable to mix the hybrid with, say, Lawson cypress in the same line. Cases have occurred where it has trouble in securing adequate anchorage on rich sites, developing a lean whilst otherwise healthy; the use of large plants with a poorly developed root systèm may be largely responsible. Propagation being by cuttings, care in obtaining material that has been well selected and properly rooted is indicated.

More ornamental types may be used where slower development is acceptable. *C. lawsoniana Allumii*, the bluest of the glaucous cypresses, narrowly pyramidal in habit, may beat *Thuja* but in some districts deteriorates if left to grow on unchecked. A close relative, with grey green foliage and slender columnar form, often distinguished as var. *fraseri*, may be preferable for this reason. *Thuja plicata semperaurescens* with leaves tinged yellow, the beautiful *T.p. zebrina* with bands of yellow and green; *Cupressus macrocarpa* Donald Gold and *lutea*, golden and bright yellow respectively though both more compact than the type; *Chamaecyparis pisifera*, the type not the varieties, but tending to thin with age; the slow-growing *C. obtusa*; the hardy and faster *C. nootkatensis*, not exacting as regards soil and with several attractive varietal forms, such as *pendula* with distinct pendulous branches; the handsome pencil cedar, *Juniperus virginiana* with ornamental offspring like the silvery *glauca; Cryptomeria japonica*, easily cultivated on deep soils retentive of moisture, var. *elegans* with feathery, juvenile foliage turning deep red in winter being particularly striking; all these illustrate colourful variations which are possible in return for a little patience.

The pines, spruces, hemlocks and the deciduous larches demand the freedom of larger country gardens to look well as single-row windbreaks. Both the Scots and Austrian pines form useful screens when young, the latter having the additional advantage of withstanding considerable exposure, sea winds and urban atmospheres. Generally, after reaching 20 ft or so, such strips become open at the bottom, when a shrub filler should be used to keep this space closed unless there is a hedge or wall along one side. Cases occur where branches are retained down to the ground on stems 25–30 ft tall and no more than 6–8 ft apart but this is not usual; much depends upon the branching habit of the trees in question. Sitka spruce, a sturdy starter, again forms an excellent windbreak until such time as lower branches tend to die off. Inadequate rainfall or soil moisture become more limiting after the trees reach 20 ft or so and may cause serious checking. Norway spruce grows more slowly, is less affected by dry spells, but suffers more from the blasting effect of wind. Both the spruces can be topped to restrict height growth, as practised on Danish heathland farms, but this is unusual in Britain. Larches need to be used in conjunction with a hedge, shrub layer or evergreen conifer, to be effective in a single line, owing to their light foliage and open crowns.

In spacious policies and grounds, where exposure is not severe and soils are fertile, ornamental conifers in avenues can ultimately provide useful wind protection, albeit accidentally. *Thuja* and *Sequoia* species are examples. If exploited for shelter, the secret lies in maintaining a fairly close spacing between individual trees and avoiding the wind whilst at the same time allowing scope for free development of the side branches.

Mixtures of conifers with broadleaved species in single rows are not worth considering for the most part. There are exceptions but success depends on both species having space for individual development and a close barrier is rarely possible in the early years. Lawson cypress, *Thuja*, Norway and Sitka spruce and silver firs, at intervals of 3–5 ft, have been frequently used to maintain low cover between poplars planted 10–24 ft apart. Lawson cypress, however, should be no nearer than 8 ft to the poplars. Willows, coppiced at intervals, interspersed amongst spruce, can also give effective shelter but spread out to catch the light. Willow, in this case, is employed as a shrub and in such mixtures one species should be shrubby in character rather than both being tall-growing trees.

Difficulty arises when there is uncertainty of the species which will become dominant. Slow growers struggle upwards and conifers in this position are apt to lose their leaders if their neighbours are whipped by the wind. Birch is notorious for its whipping. Furthermore, one or other species must provide the lower cover. Beech and hornbeam do this below Scots pine, for example; sycamore and oak persevere between larch, although the oak may need to be released year after year, but fail to keep the bottom of the belt closed. It is important for secondary species to be shade-bearing and where the main trees are interplanted with shrubs of this category, no problem arises once the former get into their stride. Not all such combinations are pleasing: evergreen shrubs beneath dark conifers are best avoided.

Comparatively few broadleaved trees, planted pure, are recommended for tall, single-row windbreaks, where branching to the ground is essential. Mature lines of parkland elms, limes and horse chestnuts look well on large properties but cannot be regarded as windbreaks. Lime avenues, with trees almost touching, form fine shelters, if incidentally; like elms, limes can also be topped when 20 or 30 ft tall to bush out and form a serviceable, leafy screen in summer though untidy in winter. Poplars in single lines, and especially the fastigiate varieties, are well known but far-ranging roots can prove a serious disadvantage. Few gardens are sufficiently extensive to employ poplars, windbreaks of which are considered in greater detail in later chapters (see Index).

For single-row structures of one broadleaved species only, it is frequently a case of one which can be grown in hedgerow fashion. Hawthorn, for instance, provides tall bushes, small trees or laid hedges. Tall screens like the famous Meikleour beeches in Perthshire and the narrow, tight-pruned 'walls' of beech and hornbeam popular in the German Eifel mountains and the high plateau of the Ardennes take several generations to develop but there are other possibilities. Many hedges have trees at intervals allowed to grow up above the general level. These do not provide the best shelter if the free-growing stems are widely spaced or leave 'windows' between the crowns and the hedge proper. Provided this is allowed for, however, there is a considerable advantage in using a dual-purpose species such as beech and hornbeam, selected stems being left to develop without restriction whilst intermediate plants are checked to give a hedge for shelter near the ground.

The Swedish whitebeam can be similarly treated and responds to side-pruning when all stems, closely-spaced, are allowed unrestricted height growth, resulting in an excellent windbreak. Alder, mountain ash, elm, lime, field maple, hazel and sweet chestnut lend themselves to such arrangements, in which individual stems become submerged in the general thicket, which looks better than having more mutilated trunks at wider intervals. Species like alder, hazel and sweet chestnut also coppice easily, thus facilitating treatment and perpetuation of the shelter.

Fastigiate trees, such as the slender, spire-like *Carpinus betulus columnaris* and the wider, perfectly pyramidal *C.b. pyramidalis* or the Dawyck beech, *Fagus sylvatica fastigiata*, develop into useful, ornamental screens but are usually too expensive for the close spacing and subsequent 'wastage' involved in providing early shelter. The same applies in the case of the Cornish and Jersey elms, whose individual stems need freedom to develop to look their best and mostly to be supplemented to give low shelter.

Evergreen broadleaves for shelter are restricted to holly, laurels and rhododendrons, all of which can in time produce a fairly tall if sprawling screen, and, in mild, coastal districts, the slow-growing, evergreen oak.

Mixing the species of leaf-trees offers far greater scope but mixtures should be simple for successful, one-row windbreaks. Good results can be obtained from alternate trees and shrubs, or 2–3 shrubs between the main species, the latter at 4½–9 ft apart according to size, or by replacing the shrub with a slow-growing, secondary species not likely to be suppressed by its faster neighbours. Beech and hornbeam and, less successfully, privet and shrubby willows fill in the space between and beneath poplars; in New Zealand Lombardy poplar lines are frequently interplanted with the vigorous boxthorn, *Lycium ferocissimum*, and a number of shade-bearing shrubs can perform the same function. But, again, species like beech and hornbeam, which are equally at home as a hedge, underwood or tall tree, should be seriously considered since they can also take over where the failure of one of the main trees breaks the continuity of the line. Hawthorn has similar qualities, though standing less shade; in single-row windbreaks, however, light is rarely limiting for thorns.

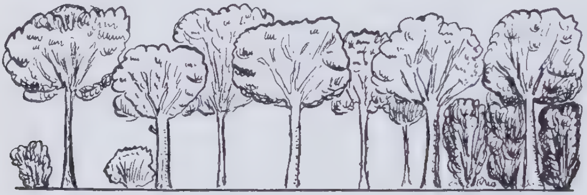


Fig. 18 *Shrubs used to fill the space below heavily-crowned trees must be capable of closing the gap effectively.*

A row of birch, sycamore, Norway maple, ash and elm or smaller trees such as whitebeam, rowan, cherry, crab and pear, interplanted with one of these three species, is easy to establish on suitable ground and can provide an efficient windbreak. With the main species, say, 4½–6 ft apart if 18–30 in. tall, at greater intervals if taller plants are used, the hedging species (no bigger than 24 in.) would be planted at 18 in. spacing, i.e. allowing 2 or 3, respectively, between the principal plants.

Large areas can accommodate forest trees that eventually attain lofty proportions; smaller areas demand trees with more modest heights at maturity. Where tall trees are wanted, both secondary species and shrubs can be incorporated within the same line. In the simple arrangement outlined above, every alternate major tree could, for instance, be replaced by the secondary species, one or more of the suggested complement of the latter giving way to shrubs. It is necessary for the underwood species, whether shrub or otherwise, to be able to keep pace with the upward displacement of the main crowns. Compact forms that leave gaps at mid-level in the windbreak are undesirable.

The spread of heavy crowns belonging to the principal trees may occasionally raise shade problems below, in spite of the benefit of uninterrupted side light. Reasonably shade-tolerant species are always recommended for the understorey, even in single-row screens. The amount of crown spread depends on the inherent character of the tree and also on the early spacing of the trees. Where height is important, too much freedom initially promotes lateral development which then occasions pruning. Side shoots that produce a low, heavily-branched crown and sap the strength that should be going into height increment must be checked until a reasonable height has been attained. This early pruning pays and, aesthetically, a windbreak of well-proportioned stems outshines poorly-formed specimens with an untidy sprawl of branches, which may break the wind but offend the eye in their winter nakedness.

Beech, hornbeam, horse chestnut and sometimes whitebeam, for example, can cast heavy shade if allowed free crown development and endanger other species in the line. Even in single-row plantings, it is better to avoid letting shade-bearing species occupy the dominant position over others that require more light. It cannot be over emphasized that it is preferable to have the densest part of the structure near the ground than amongst the crowns; heavy shade-bearers with large crowns make this difficult to achieve.

Space available should largely control the selection of species; tall shelter cannot be obtained within small grounds without some sacrifice as regards shade and root robbing. Certain species are heavy feeders: the hungry elms, for example, and to a smaller degree the ash, draw nourishment from a wide area and the fantastic spread of poplar roots in their quest for extra moisture can cause damage to drains and walls and the serious shrinkage of heavy clay soils below foundations. As with shade, it may be possible to arrange for the greatest root spread to fit in with a drive or roadway to reduce interference with garden space. Alternatively, this area can be occupied by other rows of trees and shrubs which vary in their rooting depths or mineral requirements. Two species, feeding at different levels in the soil, grow alongside one another quite happily. In this way, deep-rooting oak, walnut, sycamore and silver fir do not compete strongly with more shallow-rooting spruce, birch, hornbeam and alder. This, of course, raises the question of windbreaks composed of more than one row.

Multiple-row Windbreaks

Single-row windbreaks can be effective and break the wind as efficiently as wider belts but three or more rows present fewer problems and allow greater flexibility in the long run. The failure of the occasional tree no longer provokes a crisis; a temporary species can be incorporated for quick growth and subsequently removed, having nursed slower, more permanent varieties to continue its work; less attention is required in the early years so as to ensure a complete screen from the ground upwards; later on, as competition demands, the poorest stems can be removed gradually to favour the best; the structure is more easily replenished as one or other species approaches maturity or as a desirable variety of tree or shrub presents itself.

Where width is available for the multiple-row windbreak, which need occupy little more ground than a thick, single row, there is virtually no limit to the variety of trees and shrubs which can be included, climate and soil permitting. Monotonous lines, if long, rarely fit comfortably into a landscape and windbreaks need not be purely functional. An assortment of species often costs no more than a pure batch in comparatively small quantity, which, again, allows considerable freedom for the would-be planter.

Outside rows, which will bear the full force of the exposure, need careful selection. Fast growth is a consideration, even if such a species is not going to be retained permanently, e.g. alder, birch or poplars and Sitka spruce in suitable environments. In this case an inner row, not the adjacent row if there is a serious danger of overshading, should be devoted to a more permanent, slow-growing yet wind-firm species capable of replacing the windward edge. This practice is not recommended for very exposed sites; it is better for the windward trees to become accustomed to the exposure from an early age, otherwise they suffer when suddenly deprived of shelter. A better arrangement in such cases is to plant the temporary species in an inside row, ensuring that permanent species which may need to be somewhat tolerant of shade are not suppressed by their rapid development.

Suggestions already made for single-row windbreaks apply also to the outside rows of multiple-row structures, but there need be less emphasis on close espacement of the trees. Limes are excellent for outside rows, withstanding wind and providing shoots from the base and epicormic branches that help to make a fairly complete, though still permeable, wall of foliage. Where inside lines maintain the overall density, they can be planted 6–10 ft or even wider apart, which saves on expensive lime plants. They can also be interplanted with horse-chestnut, birch (a fast grower when well-established), whitebeam, rowan, crab, gean, beech, hornbeam or sycamore, all of which are hardy and wind-firm. Small, branchy, hardy trees are always suitable for windy edges of belts. A hedge on the windward side is also a sound proposition. One that is already in existence is invaluable for assisting the establishment of young trees in windswept districts. Windward hedges save the necessity of maintaining low cover within the shelterbelt or on the leeward side; they are a boon in later years when gaps may have to be replanted.

From the point of view of arranging for this low cover, other alternatives to hedges on the windward side are the use of species like *Thuja* and cypresses which remain furnished with branches down to the ground, the inclusion of shade-bearing underwood shrubs beneath the trees or the planting of a formal or informal hedge or shrub row on the lee side. Care should be taken to ensure that the final structure filters the wind without damming-up the air stream; thus, the more rows the wider the spacing between trees. Where there are several rows, heavily-clothed evergreens should not be used throughout. Many of these retain the shaded, lower branches; pines and spruces, on the other hand, tend to lose theirs. It may still be difficult to introduce underwood shrubs below spruce, for example, and this would be a case for creating some form of low shelter on the outside of the strip, either on the windward or leeward side.

Having allowed for the principal species, with a fast-growing, temporary variety if this is considered necessary, and also for some means of keeping the structure close at the bottom as the plantation develops, supplementary planting can be largely for effect. Widely-spaced ornamentals, selected according to aspect, find a place on the inside or leeward margin. Against a less interesting background, provided by a stereotyped row of conifers or leaf-trees, for example, laburnum, flowering cherries and thorns are easy and inexpensive. Or specimen conifers, as mentioned in the preceding pages, could be extremely effective.

The treatment of this border can be cheap or costly to suit all tastes. If it is a question of a row of shrubs to prevent ground draughts, for example, any hedging or covert shrubs provide this service cheaply. Where a more ambitious approach is desired, the choice is endless. For deciduous backgrounds particularly, red and yellow-barked forms of *Salix vitellina*, violet *S. daphnoides* and *acutifolia*, the latter with showy male catkins,

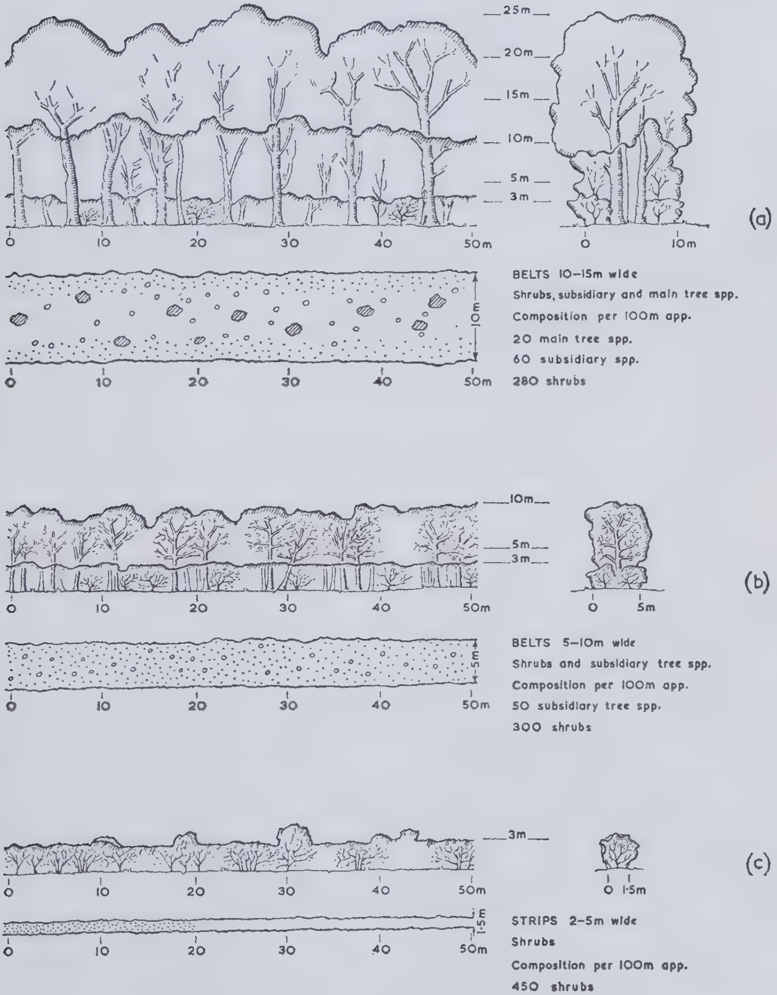


Fig. 19 An example of designs for multiple-row windbreaks used in the Rhine Valley, Switzerland (after Tanner and Nägeli).

species of *Cornus* like the crimson *alba sibirica* or yellow *stolonifera flaviramea* or, amongst small trees, the silver-white, paper birch, *Betula papyrifera* and orange-white bark of the Chinese *B. albo-sinensis septentrionalis* produce charming winter effects. The colourful autumn foliage of maples in variety, *Berberis thunbergii*, *B. wilsoniae*, *Cornus florida*, *Prunus avium*, *Quercus coccinea*, *Rhus glabra* and *R. typhina* or the grey foliage of *Sorbus aria*, *S. aria majestica*, *Pyrus salicifolia pendula*, *Atriplex halimus* and *canescens*, varieties of *Senecio* and *Olearia* or silver-leaved forms of the shrubby Potentillas provide another selection. Then there are the berrying shrubs such as the evergreen *Skimmia japonica* and the better hollies. Probably more suited to a conifer background, there are the attractive, dwarf forms of juniper, cypress and *Cryptomeria japonica*.

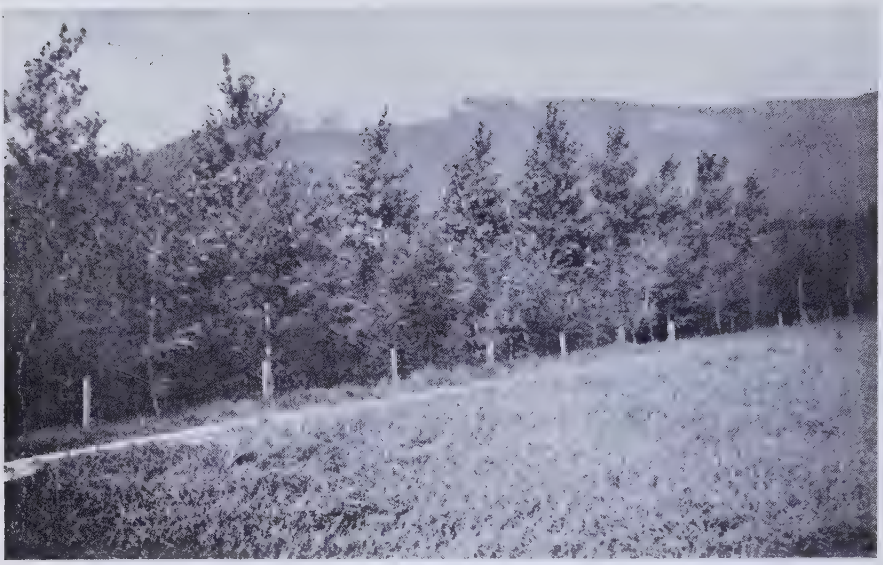
Even if space allows nothing more than a hedge on this side, colour is available from the purple-leaved and purple-flowered *Prunus cerasifera atropurpurea nigra*, perhaps interplanted with the white-flowering type or myrobalan, or from the barberries, escallonias, *Diervilla*, *Lonicera* and privets, to name but a few.

Ornamental species support the main shelterbelt but benefit themselves from the shelter. Thus, there is no shortage of material to afford all the seasonal colour or variation in form that may be demanded; reference to the extensive library of authoritative works on gardening and landscape design or to trade catalogues will confirm this.

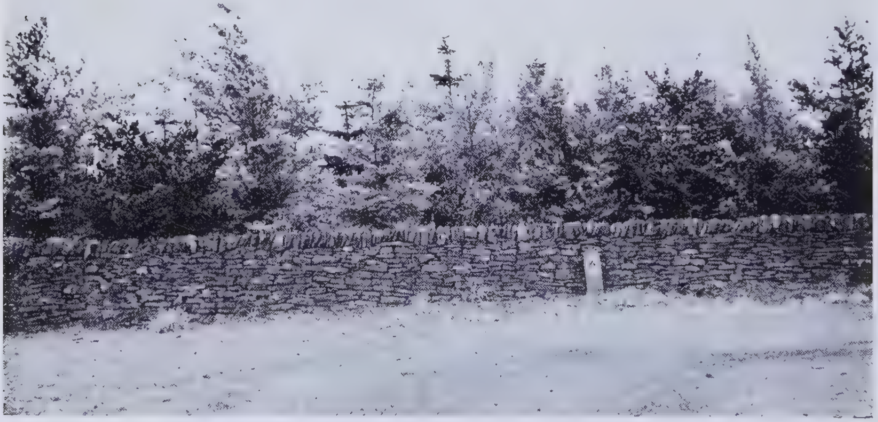
Formal gardens may suggest a formal arrangement of trees and shrubs, perhaps only one species represented in each row. Others may call for a less rigid arrangement, avoiding straight lines and sharp changes. Both can be equally effective. Line planting is necessary if a rotavator is to be used between the rows in the early stages to suppress weeds but planting in groups (see Chapter 9) can also be arranged so that the short lines within the groups are continuations of those of the surrounding matrix. Lines make planting and subsequent tending easier and in mixed plantations soon disappear when viewed from the outside; but they are by no means obligatory.

27 *Leeward side of a four-row shelterbelt at the Scottish Horticultural Research Institute, eight years after planting. First row: Sitka spruce; second row: Norway maple-beech-sycamore-beech; third row: Sitka spruce-birch; fourth row: beech with every fifth tree a copper beech*

28 *Single-row windbreak of* Caragana arborescens *on a Canadian prairie farm*



29 *Six-year-old Swiss shelterbelt, 28 yards wide. The 19 rows are composed as follows: birch; alder; birch; poplar; birch; Norway spruce; birch; alder (2 rows for coppice); poplar; hazel (2 rows); birch; Norway spruce; birch; poplar; birch; hazel-alder and birch. Rapid growth of poplar provides an irregular profile*



30 *Eleven-year-old, four-row shelterbelt at the Scottish Horticultural Research Institute, composed of beech, spruce, birch, sycamore and Norway maple in mixture. The rapid height growth of birch has had to be checked and further thinning undertaken*

PLANTING AND MAINTENANCE

Extra effort expended on proper preparation of the ground, the simple operation of planting and early tending reaps dividends that are easily lost, not always visibly so, if plants have to waste a good deal of their vigour in combating weed competition, poor rooting conditions and bad planting. Given care, trees and shrubs can gain as much as three or four years over less fortunate plantings, producing earlier shelter and a better shape.

Usually it pays to cultivate and fallow the ground over the winter before spring planting and during the summer for autumn planting. This improves tilth, promotes aeration, checks the drain of weeds on fertility and moisture and provides a better medium for growth. Eliminating competition on former grassland is essential; trees rarely prosper in the face of moisture demands of a tight turf, the proportion of rainfall percolating through to the tree roots being considerably reduced. Where cultivation is not practicable, the turf should be pared off for at least two feet around each plant. A depth of 2 in. is quite sufficient, removing not only the grass but weed seeds that lie dormant amongst the turf and in the upper soil horizons.

Manuring is rarely essential for establishing trees in most parks and gardens, other than those disturbed by building operations or with poor soils lacking vitality. Nevertheless, most trees and shrubs, not just expensive ornamentals which justify it particularly, benefit from the encouragement of leaf mould or well-rotted farmyard manure and compost dug into the bottom of the prepared pit or trench. Farmyard manure should go well below the roots but is best avoided with inexacting species, pines for example.

Pit-planting, the normal garden practice, pays in the long run and can be afforded with small windbreaks, if not in the case of farmers faced with handling hundreds of plants for larger shelterbelts. Smallish plants are the rule since they suffer least check; except in very windy situations, bigger plants succeed with proper attention during the critical, first season but with evergreens the size range is strictly limited. If time and a small plot of ground are available, money can be saved and subsequent success assured by purchasing seedling stock or small transplants the year before they are needed, or earlier if desired, and lining them out with just sufficient space for their roots to expand. Lifted when required, with a good ball of soil attached to the roots, and transferred to prepared pits in the windbreak, failures are exceptional.

Plants arriving ready for use from nurserymen can go straight into the ground, soil and weather conditions permitting, or after being heeled-in in a trench with soil loosely packed around the roots until the ground is free of frost or a more convenient time presents itself. It is important for roots to have regained close contact with soil particles and the moisture in them before shoots begin to grow, otherwise added transpiration imposes a heavy strain on the root system. Consequently, watering may be advisable to hasten the establishment of this bond between root and soil, formed by a film moisture in the presence of oxygen, so that aeration in the soil is also necessary.

Dipping plants in water before planting can be harmful, through washing soil particles off the root hairs. It is a poor alternative to puddling the roots in a fresh mixture of fine clay and water immediately after the plant is lifted in the nursery, in order to seal the root system effectively and maintain the turgidity or tension of solutions in the plant tissues. It is not effective once this tension has been interrupted and roots allowed to dry out. Only plants puddled before moving benefit from dipping in water to re-establish root contact with the soil covering.

The root tips are the active and sensitive part of the root system and explain the advantage and greater cost of the nurseryman's transplants as opposed to seedlings. Transplanting in the nursery brings the mass of wide-spreading root tips into a compact bunch so that they can be lifted entire; it also encourages a more fibrous root development with a higher proportion of active root tips.

Root growth can occur without shoot growth, not adhering exactly to the seasons. In mild weather it may go on in winter, being strongest in spring and early summer, slowing down or stopping in July and August under our conditions and renewed from September on into November. Delay in root growth has no effect on the bursting of buds. Transplanting is therefore possible from September, after shoot growth is finished, right on into the following June; but, after shoot growth has begun in the spring, only if the root system can be lifted more or less undisturbed and the water supply to the tissues not disrupted. The period of transplanting can be prolonged if the plants are lifted before root growth begins and transferred to a temporary trench, which is standard practice. Using cellar storage instead of outdoor trenches enables Canadian prairie tree planters to overcome the obstacles of a frozen winter and a short spring.

After planting, weed growth needs to be kept down by cultivation of the surface soil, by mulching or by treatment with herbicides. Developments in the last have been remarkable in recent years but chemical weed-killers should be used with caution and according to manufacturer's instructions. A rotavator gives excellent results if not allowed to go too deeply, extra care being essential with shallow-rooted species. Mulches of straw and potato haulms eliminate weeds, reduce evaporation from the soil and save the moisture for tree roots but occasionally harbour small rodents which may turn their attentions to the young trees. Black polythene sheeting or heavy paper sacks from feeding stuffs and farm fertilizers work similarly when placed around the plant and weighted down with clods or stones. This practice is particularly worthwhile with expensive trees that are difficult to establish. After a few years cultivation is no longer necessary and little further care is required until competition between the trees exerts itself.

Pruning usually refers to controlling the shape of trees for the sake of appearance and well-being. In windbreaks this may apply especially to ornamental specimens which are to be preserved as such. More often, however, the character of individual stems is submerged in the overall structure which has to be thick enough to halt the wind. Ideally, there should be no pruning but this would be a rare case. Pruning operations should be confined, however, to restricting overhanging crowns, controlling excessive competition between species or between adjacent trees where one or other cannot yet be removed without impairing the shelter, and checking height growth at a required level.

Wherever possible, topping should be avoided, except for hedges, pleached screens or similar in which the identity of individual stems is never very apparent. Lopping or pollarding of street trees, for example, can turn an otherwise attractive tree into a monstrosity, whose cancerous bulges at the end of mutilated branches stick out like sore thumbs in winter and only in summer are decently concealed by dense mops of foliage that are anything but natural.

Pruning should never be an alternative to thinning. It is just as important to remove a tree at the optimum time as to plant more initially than are required in the final composition. Yet, thinning is the most neglected aspect of arboriculture. It is merely the sacrifice of the few for the greater benefit of the many which remain and should not be postponed once the need is apparent.

In order to maintain a fairly complete screen from a single row of most broadleaved species, some pruning is inevitable. Poplars in their considerable variety form a screen more rapidly than any other group but no spacing recommendations suit all. Fastigiate varieties can be planted 6 to 8 ft apart; other types at that spacing soon demand more room if free height growth is allowed. Poplars like light, which is why they usually fare better in single lines or in parallel rows 15 to 18 ft apart, often more. Where light intensities are not high, as in northern Britain, it is essential to keep poplar crowns free of competition. In all but the most tight-crowned forms at 6 to 8 ft intervals, by the time the trees are 15 to 20 ft in height the intertwining of lateral branches will cause suppression of some unless they are cut back to 3 or 4 ft from the stem.

Eventually, alternate trees have to be removed in order to allow a crown width appropriate to height. Nevertheless, this is preferable to planting wide apart and losing the benefit of early shelter. Once the trees develop good crowns, shaded branches towards the bottom die off quickly in some poplar varieties, more slowly in others. This loss must be compensated by some other form of wind barrier near the ground, a shrub row, for example. The same applies to most light-loving broad-leaved trees; shade-bearers maintain the lower shelter rather longer and there may be less occasion to prune.

The maintenance of a sound, long-lasting windbreak may extend over several generations. Given a good start, the time and money expended become virtually insignificant. All that regular treatment amounts to is good husbandry: removing weak and ailing stems, replenishing gaps and releasing the overcrowded, with an eye to keeping the structure close without being too thick in order to filter the wind and provide the maximum shelter that will work wonders in the bleakest surroundings.

8 Windbreaks for Special Purposes

SITUATIONS NEAR THE SEA

Places near the sea encounter constant, if not always uncongenial, winds and periodic, salt-laden gales. Salt spray may travel considerable distances inland but it is the coastal strip, two to four miles wide, that suffers most, both during the long growing season allowed by mild conditions and in winter. Occasional salt storms blacken flourishing gardens in a few hours and shelter becomes essential.

Wind and salt limit the number of tree species that can withstand considerable exposure to both. Repeated assault by sea winds shears the side nearest to the sea of most trees, causing die-back of the twigs on this side whilst on the other shoots grow more freely. As a result, the whole tree leans inland. Frosts are rare but sharp drops in temperature, as when warmer, tropical air is suddenly displaced by a polar stream, play havoc with young shoots that may fail to harden-off in the normally mild winter. Nevertheless, trees and shrubs can be selected to tolerate coastal conditions, provide shelter and, on the west, create an environment that can make full use of the warm air rising from the Gulf Stream once the winds are excluded.

Winds off the sea prune coastal plantations to minimize resistance to their flow and the canopy formed by the stunted crowns slopes upward from the shore with remarkable uniformity. Each successive rank of trees grows taller than the one in front, following the line of deflection of the wind stream. In the face of such severe competition from the exposure, one should be prepared to forget timber production and abandon hopes for tall, well-formed trees. The shaping of the profile on the windward edge also restricts the filtering action that is generally expected of a good windbreak; in this way the sheltering range is shortened, frequently giving little wind protection at leeward distances beyond about twelve times the height of the innermost row of trees. Limitation of the sheltered zone is unavoidable when the canopy adopts a markedly streamlined form but the degree of wind-pruning can often be reduced.

The scourge of newly-planted trees and shrubs is desiccation through excessive transpiration demands and the further claims of saline deposits on the leaves. This is why tall plants should never be introduced to an exposed site and coastal situations especially. Small plants, 12 to 18 in. in height, rarely more, suffer less because they lie close to the surface, where frictional drag produces a certain amount of shelter. Given this respite to develop their roots and fasten on to the moisture held in the soil, they are better equipped to tackle the harsher conditions encountered as they grow taller. They outstrip bigger plants subsequently in both rate of growth and form.

Some form of temporary protection on the windward side of a planting achieves the same purpose and both methods are advisable. But it is better for this screening to be fairly open so that the plants are gradually conditioned to their environment right from the start. Close screens can do more harm than good, young trees adapting themselves to artificial conditions and suffering acutely when they overtop the barriers. Leading shoots of trees are always most vulnerable; thrust up into a vicious wind accelerating over the top of a solid fence or wall they are inevitably shorn off. Walls around exposed plantations appear to predetermine the height reached not only by trees in the windward row but also by those many yards behind. At Gosford, East Lothian, tree height fifty yards inside the coastal strip is related to the height of the outer wall; as the latter changes so does the effective height of the shelterbelt, the angle of shearing remaining constant. Height growth, in the long run, would presumably have been better had there been no solid barrier in front.

Brushwood, held between stakes or pig netting, will suffice for this windward barrier as will the slatted, slate fences of North Wales, cleft chestnut paling, snow fencing and the less dense types of willow hurdle. The rougher the tops the better, in order to break up the concentration of the air stream passing over. Wherever possible, something hardy should be set in front of the screen, where it derives some protection due to the windward shelter effect and prepares for the ultimate removal or collapse of the screen. For this row particularly, but for others also, select some shrub or tree that is cheap and reliable and has shown its capabilities in the district. Trees and shrubs have to be attuned to the overall climate and the soil as well as to the exposure. Those that prosper in the chalk of the south coast may reject the Silurian soils of Wales and those that do well in the latter may fail to respond to situations on similar formations in Scotland, owing partly to the lesser benevolence of the Scottish winter. Long lists of trees and shrubs tolerant of seaside situations can be found in the appropriate reference books, but these have to be carefully vetted before selecting for one's own district. One can be ambitious and try a wide variety of these, often with considerable success, but money can be wasted if too much hope is pinned on something with no local reputation.

Many species that thrive under average conditions can be severely checked or killed by the exceptional spell of bad weather. At Rosewarne, Cornwall, the abnormal cold of January and February 1954 killed *Cupressus macrocarpa* and various species and hybrids of *Olearia*, *Pittosporum* and *Veronica* used for hedges. Strong winds in May frequently shrivel and scorch newly-flushed trees and shrubs. A September salt storm on Cardigan Bay has been observed to destroy young shoots of *Escallonia punctata* within a couple of hours, although this robust shrub is normally safe in the area. A single gale in September 1961 spread serious salt damage over a very wide area in western

Scotland, affecting species not usually subjected to such injury. Whilst most plants of a perennial character recover in due course, time is lost and this is unfortunate when shelter is wanted quickly.

In seaside windbreaks, the outside rows bearing the brunt of the salt winds matter most and are the key to success. Trees or shrubs used here must be reliable, if necessary at the cost of appearance. Orcadian winds, for example, have been countered by using local willows in conjunction with the salmonberry, *Rubus spectabilis*, attractive in flower but a notorious invader. Observation showed that these grew sufficiently well in the neighbourhood to give shelter. This simple practice entails less risk and can produce earlier benefits. Elder, again, hangs on along the coast from Wales to Shetland, where it flourishes in the teeth of Atlantic gales, and would be high on any list where choice is limited.

Species that spread by suckers do well in coastal areas. Like the salmonberry, whose encroachment on gardens can be controlled by maintaining a deep trench behind or sinking corrugated iron sheeting vertically into the ground, the Chinese tea-tree, *Lycium chinense*, provides a vigorous hedge a little north of Aberystwyth, in spite of continual drenching with spray. Further north, it threatens to colonize areas of shingle. The suckering of the white poplar (*Populus alba*) can also be a useful feature. Where there are other rows behind, root spread from the first one or two rarely matters; when it encroaches on garden space, control methods or alternatives have to be sought.

Exposed windbreaks should have at least one row of shrubby plants on the outside as a first line of defence. Behind this there may be more latitude of choice. If it is possible to establish trees of reasonable height and form in a second or third row, bearing in mind the condition of trees in the district and also any improvements in the soil which might be feasible in order to give the plants a better chance, there is much to be said for creating a semi-permeable structure to sieve the wind. Thus, too many rows of a thickly-clothed species would be undesirable. Coastal belts of two, three and five rows can often prove successful but they are difficult to repair or regenerate without taking in more ground. It is preferable to plant more rows if space allows, varying the composition to avoid too solid a barrier and to allow greater flexibility in subsequent treatment.

Where exposure is so severe as to threaten to streamline the planting, in spite of the use of hardy, salt-resistant species, one is less concerned about increases in density than about obtaining height. The greater the width of the strip, the higher will be the trees on the leeward edge. Even if a smooth, wind-pruned canopy develops, attempts should still be made to break up the uniformity by introducing particularly vigorous trees, probably in small groups cleared for the purpose. Temporary protection may enable their leading shoots to break through the canopy and so roughen the surface. An old remedy, for the sake of example, was to place turf along the copings of walls. Wire netting, suitably treated for greater durability in the salty atmosphere, would act similarly. As a means of dealing with the canopy of large windbreaks (see Plate 23), it might be worth considering erecting sections of stout trellis at suitable intervals, mounting them on poles protruding above the crown level; behind these the crowns would rise above the maximum wind-shear and ultimately produce an irregular canopy with greater roughness to hamper the wind and afford better shelter.

Trees to grow tall along coasts require careful selection; they need immunity to salt winds and to be satisfied with the climate and soil. Even then they may never make handsome specimens but gnarled and twisted stems harmonize with rugged surroundings and are not as undesirable as they might be at Kew or Cambridge. The more exacting the exposure, the greater is the need for shelter and anything which breaks the wind becomes acceptable. But the problems of selection, though difficult, are not insuperable.

Of the conifers, the Monterey cypress (*Cupressus macrocarpa*) is noted for its resistance to sea winds, growing rapidly and anchoring itself well if given plenty of room from the start, but it cannot stand cold or cutting. Restricted to the south and west coasts, succeeding quite far north on the latter, it is a popular species for soils of reasonable depth that allow good root-hold. More promising for cooler situations but more expensive, the hybrid *Cupressocyparis leylandii* has proved its worth against exposure to winds off the sea in several places and deserves a trial elsewhere.

Again confined to warmer areas, the Monterey (*Pinus radiata* syn. *P. insignis*) and maritime (*P. pinaster*) pines tolerate sea spray. The latter achieved fame for its success at Bournemouth and can be relied upon for most places in the south, although the Monterey species is easier to establish if planted from pots very early in life and does not usually suffer the same stem deformation. The Austrian pine (*P. nigra* var. *austriaca*) is outstanding for resistance to exposure, both inland and near the sea, thriving even on chalk and limestone and unexacting as regards temperature. It is more heavily branched than the Corsican variety, *calabrica*, which is usually preferred for plantation purposes except on chalky ground. Corsican pine likes greater warmth and suffers when planted too near the sea front; further back it does better and has earned a reputation for its success on sand dunes at Holkham, Norfolk and Culbin, Morayshire.

The Aleppo pine (*P. halepensis*), common in the Mediterranean and notably drought resistant but difficult to establish and not very hardy when young, and the hardier Bishop pine (*P. muricata*) are often recommended for coastal planting but need to be used cautiously. The black pine from Japan (*P. thunbergii*) has limited possibilities in mild areas, being successful on sand dunes in Ireland and mainly used for reclamation work on sands. The native Scots pine (*P. sylvestris*) is a good stand-by for inner rows of windbreaks near the sea. Though scorched and blasted if fully exposed to salt winds, it will survive if well rooted. Stumps of old pine forest stretch far out at low tide at Ynyslas in Wales and elsewhere around our coasts. The extremely tough and hardy mountain pine (*P. mugo*), more bush than tree, stands any amount of wind but not too much spray and is particularly useful for the margins of high-lying shelterbelts, even fairly near the sea. Similarly, the lodgepole or shore pine (*P. contorta*) is a species for harsh situations and poor ground and some provenances are fairly tolerant of winds off the sea if not of repeated salt action.

Sitka spruce (*Picea sitchensis*) withstands appreciable exposure in coastal districts where there is adequate moisture but should not be subjected to spray continuously. In coastal forests the edge trees recover remarkably well from occasional salt-burn and inside trees show little effect as a rule. Of the silver firs, *Abies pinsapo* likes chalk cliffs in warm, dry parts of Britain but needs some shelter at first. The well-known Monkey puzzle or Chile pine (*Araucaria araucana*) from the southern hemisphere prospers as an individual tree or in small clumps on the shores of exposed sea lochs in Argyllshire and appears immune to wind; it is less respected on the Welsh coast where it acquires a dejected appearance.

Amongst broadleaved species, white poplar has considerable merit, including the ability to tolerate a fair amount of salt-water flooding, to which all conifers, sycamore, ash, beech and black poplars are highly susceptible. Tamarisk, sea buckthorn and *Lycium* are others which are mostly resistant to salt-water floods. The grey poplar (*P. canescens*) is another tall grower near the sea. Some of the hybrids, such as *P. serotina*, may succeed but, for the most part, poplars and willows are not recommended for a first line of defence in a coastal windbreak fully exposed to sweeping winds off the sea. White poplar is best but all poplars and willows, including *Salix alba* which can also do well near the sea, need moisture and resent dry positions and thin soils, especially over chalk. The shrubby sallow, *S. caprea*, is of course easy to deal with, suffering some of the worst conditions of the British climate, but it should not be to the fore to catch too much spray.

Often badly battered, leaves blotched brown with salt-burn, sycamore is an outstanding shelter tree on all but high ground of low fertility. Also, ash (*Fraxinus excelsior*), wych elm (*Ulmus glabra*), Cornish elm (*U. stricta*) and Guernsey elm (*U. s.* var. *sarniensis*) come well to the fore for situations near the sea although none may be entirely unaffected by the sea winds.

The common wild pear (*Pyrus communis*), rowan (*Sorbus aucuparia*), whitebeam (*S. aria*), the last especially useful on chalk, withstand the exposure when spared the constant attentions of wind-borne salt. The local whitebeam in Cornwall often appears under the name of *S. latifolia* and is highly suitable for shelter; the native species in mid-Wales is frequently self-established on plantation margins on the coast.

The evergreen or holm oak tends to be overlooked because of its slowness but is recommended for long-term shelter in mild areas. Remarkably tough, responding well to clipping as a hedge, it also forms a dense-crowned tree; the Earl of Leicester's avenue of *Quercus ilex* at Holkham is a particularly fine example.

Many species succeed in inside rows of seaside shelterbelts, away from the blasting effect of salty winds: ash, beech, birch, hawthorn, hornbeam, sessile and Turkey oaks, Norway maple and grey and black alder, the last for damp situations. Mixtures avoid the danger of concentrating on one species and, if space allows, a selection including trees with different growth rates and degree of shade tolerance makes for permanence.

Some of the taller-growing shrubs can provide an adequate windbreak, even from a single row. The tamarisks (*Tamarix anglica*, *T. gallica*, *T. pentandra* and *T. tetranda*) are widely used in the south-west and appear on the Suffolk coast. All withstand wind but the last two are less inclined towards salt spray. They are, however, difficult to train and become rather open, particularly in winter. Similarly, sea buckthorn (*Hippophae rhamnoides*) is sprawling and gappy when it reaches 15 ft or more in height. It is probably most successful on the East Lothian coast, more so than at the same latitude in Denmark or in Cornwall. As a single-row windbreak in Scotland it suckers freely and regenerates itself on the edges, requiring a fair width of strip such as might accommodate two or three rows of trees and less rampant shrubs. For edging coastal shelterbelts and plantations where the locality suits the species and where spread would not be a disadvantage it has possibilities.

Other shrubs which can go right down to the shore to face the spray include *Atriplex halimus*, *Euonymus japonicus*, *Griselinia* *littoralis*, *Lonicera nitida* and the smaller *L. pileata*, *Lycium chinense*, the frost-hardy but slow-growing *Olearia haastii*, blackthorn and the common and golden elders. Elders suffer from salt-scorch but are remarkably tenacious. Further back there is more choice: brooms (*Cytisus*, *Genista* and the Spanish *Spartium junceum*); *Buddleia; Cornus alba; Cotoneaster frigida* and *C. henryana; Escallonia macrantha; Rosa canina*, *R. spinosissima* and *R. eglanteria*. Shielded from the worst of the salt winds, additional suggestions are: *Aucuba japonica; Berberis stenophylla*, *B. darwinii; Bupleurum fruticosum* (excellent for exposed cliffs in the south, well adapted to chalky soils and to some overhead shade, growing to 5–8 ft); *Elaeagnus glabra;* escallonias such as 'C. F. Ball' and 'Donard Seedling' and two important varieties raised in Cornwall, *Escallonia* 'Red Hedger' and 'Crimson Spire', the latter more upright and having grown 7 ft in four years at Rosewarne; *Olearia macrodonta* and several other varieties; *Pittosporum crassifolium*, *P. ralphii; Senecio monroi;* some shrubby veronicas, such as *Veronica salicifolia;* common juniper; and gorse, *Ulex gallii* in the south and *U. europaeus*, which stands more frost, elsewhere. Common dogwood (*Cornus sanguinea*) and the Scotch laburnum (*Laburnum alpinum*), though deciduous, can render good service.

Lists could be longer but can provide only a guide. Experiences with trees and shrubs differ up and down the coastline, often unaccountably, and local evidence is invaluable. For potential planters in the south-west particularly, the extensive trials of sheltering species conducted by the Ministry of Agriculture at Rosewarne provide a unique opportunity for comparison and selection.

The seaside gardener may be content with a hedge, especially if there is limited space or the view is too precious to lose. The chief characteristics to be sought are: a hedge plant suited to the site, bearing in mind the chance of frost which greatly restricts the choice amongst maritime species; something comparatively cheap, easy to transplant, relatively quick-growing and whose success is fairly well assured; a species capable of being trimmed once or twice a year to keep it thicker at the bottom, unless it is satisfactory when free-growing.

Taller screens may be composed of a single row of the taller shrubs or cypresses or, when major tree species are used, from two or more rows, the windward row consisting of a shrub. A line of pines, for example, needs the shrub support as a nurse in the early stages and as compensation for the sparseness of the lower branches later on. Further support can be derived, in a garden or park, from a backing on the leeward side of a shrub border forming more a part of the garden display than part of the windbreak. An important point is to look for impending failures in the outer defences and to deal with these promptly.

Occasionally one may have to contend with patches of bare sand liable to blow. Small areas present little difficulty; many species, e.g. *Rosa rugosa* and broom, thrive on almost sterile sands or, alternatively, organic matter in the form of farmyard manure, seaweed, compost or peat can be incorporated or used as a mulch to improve soil conditions for other plants. Larger areas can be thatched with brushwood pegged down against the wind before planting with broom in thick strips across the wind direction. Pines, alder, birch, aspen or sea buckthorn, for example, can be introduced in between once the cover is established.

PUBLIC PARKS AND RECREATION GROUNDS

Providing shelter in public parks and recreation grounds is simply landscaping with the additional objective of checking the wind for the benefit of their users. Warm, summer days draw hordes of people to parks and open spaces but only the more sheltered receive regular use in less congenial weather; not many are conducive to loitering during the long months of winter and early spring. Botanic gardens hold greater attractions, not just for their intrinsic interest, but because the grouping of trees and shrubs fosters an environment that tempts one to linger. Biting winds are dissipated amongst the branches and foliage without losing the beneficial circulation of air. On all but still, foggy days the freshness of the atmosphere is maintained but this is 'fresh air' in the accepted sense, not the meteorologist's 'fresh breeze' of about 20 m.p.h., which is hardly necessary for outdoor enjoyment.

Parks need not be copies of botanic gardens to provide the sort of protection required to rear a range of exotic plants, nor need they be fragmented into a series of sheltered pockets. Spaciousness can be maintained along with local shelter beside well-placed clumps of trees or alongside much-frequented paths. Long shelterbelts have their purpose where they can abate the wind and at the same time screen unwanted views of factories, tenements or allotments on park perimeters. They can also provide better conditions on playing fields, for which any of the arrangements suggested for larger gardens or nurseries can be adopted, taking care not to overdo the shelter and restrict drying-out of the turf after rain. For this reason it may be advisable to concentrate the planting on the north side, leaving the south open to sun and milder winds. In most open spaces it is not necessary to shelter large areas as with farm shelterbelts; clumps and small groups of trees and shrubs give adequate protection and their number and distribution can vary in proportion to the windiness of the site. The coolness of the wind can be tempered without creating stagnant pools to fill with frost and ground fog at the slightest provocation.

Avenue plantings are serious offenders in many parks. Several feet of bare stem below dense crowns that touch to form an almost unbroken wall of foliage can remove all pleasure from walking along the paths between. On cold, windy days the paths unlined with trees or with only very young saplings alongside are preferable. Crowding of the stems and lack of low cover are responsible for this criticism. Formal avenues depend for appearance on uniformity in tree size and on an interval between stems appropriate to the height so that the identity of each individual tree is retained. It is better to thin out the trees as they require more room; the removal of alternate trees in the first of two rows of planes bordering Birdcage Walk, Westminster, has improved appearances considerably. This practice reduces the jetting of wind between the bare trunks of overshaded walks and affords greater comfort to pedestrians.

Avenues are essentially ornamental but should not be created at the cost of draughtiness. Lining city and suburban roads, they present no such problem of accelerating the wind because buildings behind make their own contribution to the general shelter. It is when the avenue cuts across a sweep of open park that trouble arises. Filling in these avenues with smaller trees and shrubs to close the wind channels means sacrificing the feeling of open-ness and any side views that might exist. In such cases the trees should be no closer than the average street trees so that they do not greatly upset the wind pattern and cause discomfort.

Some avenues provide shelter incidentally and the best of these are undoubtedly those of sequoias or limes, associated mostly with country mansions. Narrow pyramids of foliage meet near the ground to form an excellent windbreak but height allows the tops to stand out as individuals.

Lessons can be learned from the clumps and groves laid out around the great houses of the country during the eighteenth and early nineteenth centuries, for ornament more than utility. The name of 'Capability' Brown will long be associated with this branch of landscape design, if not always with respect. Brown chose sites for his clumps with extreme care but frequently fell short as regards their composition. The trees themselves, commonly beech, were arranged in a formal manner and left untouched for a number of years until thinned to develop individual trees. Uvedale Price in 1810 condemned them for their tasteless character and pointed out the anomaly of replacing the formal style of stately avenues and suchlike with an arrangement that was equally formal but lacked the aesthetic appeal of its predecessor. Had the planting been planned for variety of colour, form and rate of growth its critics might have been satisfied.

Shelter for public parks could be planned on these lines, the scale of clumps depending on the extent of the ground. There need be no limit to the minimum size: a group of three or four conifers, feathered to the ground, can be ornamental and provide a sheltered nook but, if unfenced, continual attention from dogs and children may be liabilities as far as the lower branches are concerned. Fences may be undesirable for amenity but necessary for management; they are easily camouflaged by shrubs that grow out and through them. Economies in fencing favour larger clumps, possibly having perimeters that will just take one, two, three or more complete rolls of wire netting. Circles with diameters of slightly more than 15½ and 31 yards will, for example, take one and two 50-yard rolls, respectively, to avoid cutting and wastage. Round clumps are not necessarily the best; kidney shapes, set broadside to the wind that needs to be discouraged, e.g. north to north-west in winter, north and east in spring and west to south in summer, give more shelter and often fit more snugly into the surroundings. Any piece of elevated ground can be utilized to extend the range of wind abatement.

Clumps of planting can also be sited to take advantage of other environmental features, such as making a focal point of a particularly fine building, screening another that is less interesting, whilst breaking up the area without losing the feel of spaciousness. Rigid lines of trees that divide green areas into geometric parcels with no form of continuity need to be avoided. Some public parks, like Edinburgh's Meadows, criss-crossed by concrete paths which successive coronations or jubilees have lined with avenue trees, have lost their character in a maze of triangular enclosures. Ethics of landscape design are beyond the scope of this book but no practised eye is required to recognize the brilliant opportunities to exploit the intrinsic amenity of a site which so often fail to be grasped. Where these qualities are obscured by existing trees, there should be no sentimental barrier to the removal of some, at least, of the latter, provided further planting of a more suitable nature is undertaken.

The selection of species should be governed by site factors and the height required. This is a case for taking a very long-term-view to satisfy future generations. Tall trees may ultimately shut off distant prospects that ought to be retained and here resort can be made to smaller trees which will avoid this drawback. The ideal for clumps might appear to be a mass of trees and shrubs in intimate mixture, perhaps with an edging of shrubs, but this should not be undertaken indiscriminately. There is no reason why one should not create an ornamental arrangement of specimen trees but it is essential to try and visualize how this will appear at various stages of development. More attention will be required throughout because every tree must be accorded adequate room and enough of each species must be planted initially to allow for natural wastage and thinning.

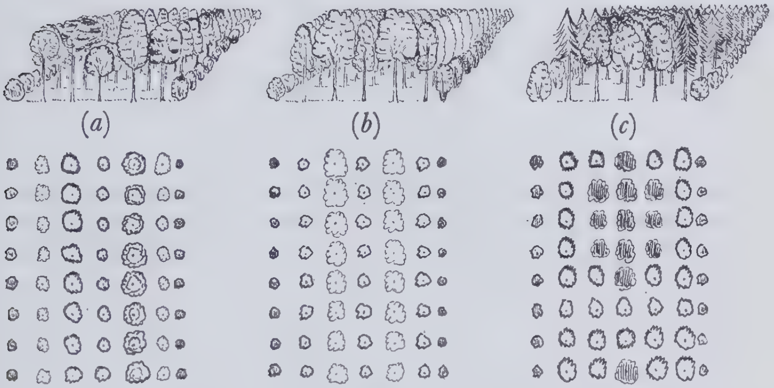


Fig. 20 *Examples of mixed composition:* (*a*) *'line by line' mixing, each row of a different species;* (*b*) *alternate rows of tall, light-demanding trees and shorter shade-bearers;* (*c*) *mixing groups of hardwoods within a matrix of conifers.*

There are many ways of achieving a suitable mixture. A simple method, borrowed from the conventional American Plains windbreak, is to plant several rows, each of a different species, at intervals of probably 10 or 12 ft to allow for mechanical cultivation between during the early years of weed competition. Tall trees may be confined to a central row or planted in alternate rows; in both cases, adjacent rows should be capable of enduring the overshading which will ultimately arise. This arrangement requires little tending until the planting closes canopy and serious competition begins, at first within lines and then between adjacent rows. An alternative is to adopt a mix-

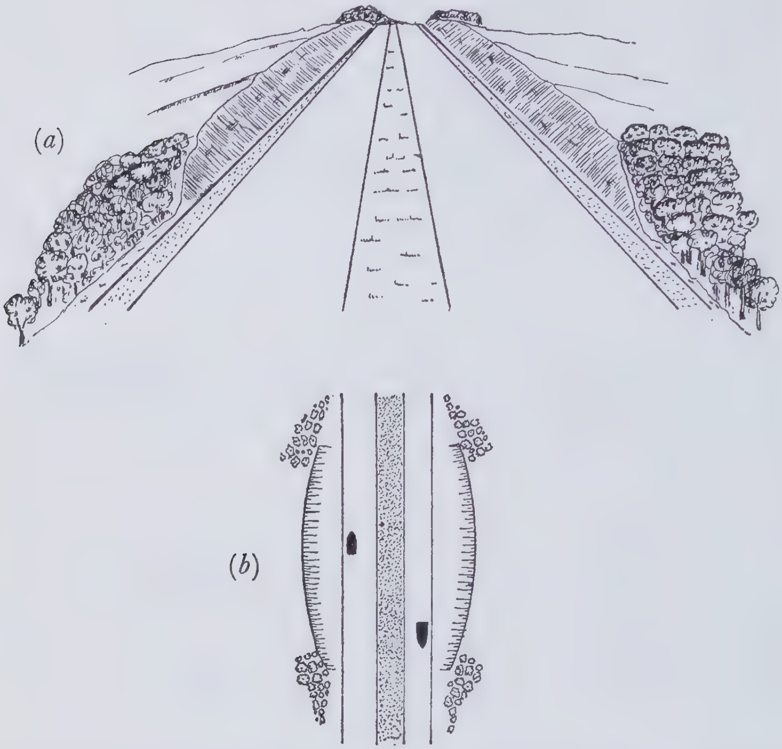


Fig. 21 *Suggested arrangement of planting to check cross-wind gusts near cuttings on highways.* (*a*) *general view;* (*b*) *plan of arrangement.*

ture by groups of from 3 to 13 trees dispersed throughout a matrix formed by a secondary or underwood species at intervals of from one-third to two-thirds of the estimated maximum height, depending upon crown spread. Each group produces one tree in the final composition. Groups containing slow-growing species might be placed towards the centre of a clump for extra protection. Closer mixing by groups is possible, provided those of trees inclined towards heavy crown development are not allowed to encroach upon their neighbours. More attention will generally be necessary and all trees in some groups may have to be removed entirely as age demands unless the arrangement provides for those trees between the tallest to accept a subordinate role as shade-bearing understorey.

Clumps formed by a single species are even simpler to establish and may not be undesirable. Their appearance can be heightened by a border of smaller, more ornamental trees and shrubs. Close planting at, say, five feet apart, as in normal forestry practice, would be most suitable for this, allowing plenty of material from which to select the final stems.

The established plantation should, by the time it has reached 6–8 ft in height, present the appearance, from the outside at least, of a reasonably dense thicket. Otherwise, it will be too thin to give good shelter. With clumps, density as it affects aerodynamic penetrability is comparatively unimportant once the minimum has been exceeded. Very dense clumps will cause greater acceleration of winds deflected round the sides and, where the clumps are sufficiently large, it would be advisable to thin these out towards the margins. There might also be some case for adopting a slightly increasing espacement between trees, from the centre towards the outside, during the actual planting.

Vandalism is the greatest scourge of amenity planting in Britain. Education in social responsibility that may eventually provide the answer takes time. Meanwhile, unwanted attentions can be discouraged by a border of low, thorny species, indigenous or exotic. Hawthorn, blackthorn, *Robinia pseudoacacia*, barberries, shrub roses and briars reduce the risk.

Another practical aspect is cost of upkeep but small windbreaks entail comparatively little maintenance once established. Competition removes the need for regular pruning to obtain symmetrical crown development, often undertaken with avenue trees. In mixtures occasional pruning may be warranted but timely thinning should be the standard measure for regulating development. A sound mixture, based on growth rates and light requirements of the species concerned, should provide an understorey to stand in the shade of the main trees and make the task of thinning easier as well as the windbreak more effective. In general, less attention need be expended on tending than is usually devoted to a few free-standing specimens.

Shrubs on margins can be kept in check if desired but, if low upkeep matters, they need not be trimmed as in a suburban garden. *Aucuba*, *Berberis*, *Buddleia*, *Cotoneaster*, *Daphne*, *Philadelphus*, *Ribes* and *Rhododendron* require little pruning and are all suitable for town planting. Variety can be in keeping with the setting but to make up windbreaks of expensive collections of trees and shrubs is undesirable and a waste of money and labour. Inevitably, some must be sacrificed for the betterment of others and conditions which obtain at the start cannot be upheld indefinitely. A clump of trees and shrubs is a viable complex and the emphasis should be on providing an association of species that are reasonably compatible and not all struggling for supremacy.

A further point concerns the autumn leaf fall. Some park authorities spend enormous sums sweeping up and burning leaves. With clumps of trees many leaves fall inside and, if there is a good shrub border to keep out the wind, decompose to form the organic matter on which forests are sustained. High winds cause other leaves to lodge round about; if necessary these can be collected and dumped beneath the trees. As an additional step, the advisability of using species with heavy crowns or large leaves might be considered. Horse chestnut, for example, has large leaves that are lost early in dry seasons or near the sea; elms lose theirs quickly and in a few days form greasy layers on paths; fallen leaves of beech, alder and holly lie for a long time. Whereas oak sheds its leaves slowly; lime litter decomposes quickly; small birch leaves present little problem; old conifer needles as they are shed spread very little. These are minor points but can save on maintenance costs.

Lists of species for town planting generalize through disregarding the fact that atmospheric pollution experienced by trees and shrubs in city parks varies enormously in degree and content. Species that withstand the smoke of London or Glasgow may be unable to cope with chemical impurities poured out by industrial plants elsewhere. Furthermore, a tree that is otherwise content with its situation is better able to withstand a polluted atmosphere.

Sulphurous gases are the most damaging and it has been estimated that five million tons of sulphur dioxide are generated annually in Great Britain from coal burning. To this must be added fluorine compounds, also released during coal consumption, carbon monoxide from motor vehicle exhausts, arsenic from smelting, chlorine fumes, oxides of nitrogen and alkaline dusts from chemical manufacturing. Any country with a concentration of industry or population encounters problems associated with growing trees and shrubs. Foliage on city trees is often smaller and paler, whilst deposits of soot and dust restrict breathing, transpiration and photosynthetic activity. Deposits may contain toxic or corrosive materials; leaves moistened by rain may attract harmful gases that are soluble on their surface.

Atmospheric pollution shows a seasonal variation in severity; some species escape serious damage because of the time they break leaf or shed their foliage. Deciduous varieties escape the period of greatest domestic fuel consumption and generally have a greater recuperative power than conifers. Meteorological conditions are also involved: frequent temperature inversions prevent dispersal of pollutants and increase their concentration so that industrial valleys may be particularly prone to attack. But the extent of the problem is mitigated by soil conditions; trees on fertile sites, also younger trees, are more resistant to smoke and fumes than those on poor ground.

Conifers, with the exception of Lawson and Monterey cypress, juniper, Japanese larch, Austrian pine, Douglas fir, thuja and yew, rarely succeed in industrial areas, which was the reason for the removal of the National Pinetum from Kew to Bedgebury in 1924. Deciduous trees are more tolerant, especially those capable of fast growth, species with hairy leaves or scaly bark and others capable of producing new shoots fairly readily when injured, as, for example, the London plane. Alder, ash, beech, birch, elm, hornbeam, horse chestnut, lime, maple, Turkey oak, pear, poplar, whitebeam and willow are all fairly resistant and the choice is usually considerably wider than this. These trees are familiar and inexpensive but will satisfy most requirements. If not, their ornamental varieties are available at extra cost: cut-leaved alder, *Alnus incana laciniata*; weeping wych elm, *Ulmus glabra pendula*; fern-leaved beech, *Fagus sylvatica heterophylla*, and purple beech, var. *purpurea*; Corstorphine plane, a variegated sycamore, *Acer pseudoplatanus corstorphinense*; non-fruiting horse chestnuts (which may be an advantage) like the double-flowered white, *Aesculus hippocastanum flore pleno*, and the pink, *A. carnea* (*rubicunda*) and *A. plantierensis*. The red and scarlet oaks, *Quercus borealis* and *coccinea*, are other ornamental trees that are reasonably smoke-resistant.

More exotic species which might find an occasional place on the edges of windbreaks away from the wind are the maidenhair tree, *Gingko biloba*; tree of heaven, *Ailanthus glandulosa*; cucumber tree, *Magnolia acuminata*; honey-locust, *Gleditschia triacanthos*; tulip tree, *Liriodendron tulipifera*; Indian bean, *Catalpa bignonioides*; false acacia, *Robinia pseudoacacia*. All these are more suitable for the south; for the north the various cherries, rowans and crabs are more appropriate. Shrubs for town planting are numerous; in addition to those already mentioned earlier in this section *Deutzia*, *Forsythia*, *Griselinia*, *Hydrangea*, *Hypericum*, *Ilex*, *Osmanthus*, *Rosa*, *Syringa*, *Veronica* and *Weigela* do not object to smoke if the climate and soil are suitable. Further possibilities will be revealed in local gardens, a very valuable guide to selection.

The establishment of trees in urban areas is not difficult in spite of the attendant risks, not least from the public itself. Yet many authorities fight shy of planting groves and clumps and overdo the lines of cherries and almond. Old and over-mature trees tend to be pruned and preserved at great expense to funds that could be more usefully disbursed in new planting. Tree Preservation Orders, far from inculcating a proper attitude towards tree planting, frequently do more harm than good and fail to provide for future generations. Only regular replenishment can maintain a continuous supply of town trees. By all means let us preserve the old and the good but not to the detriment of new planting. The removal of old trees which have outlived their usefulness and their replacement with vigorous, young stock should be a continuous process. How many local authorities, planning committees, park superintendents or architects, if accepting this in principle, put it into practice?

NURSERIES AND ORCHARDS

In nursery, market garden and commercial orchard, loss of productive area normally used to capacity rules out wide windbreaks. However, with good soils and an environment favourable from most aspects, trees and shrubs grow readily and give satisfactory windbreaks in record time from four or five rows and, most frequently, from one or two. Practical experience of weather's effects on cash crops has placed market gardeners, more than anyone else, in the lead as regards employing windbreaks; the fact that they do not expect plants to prosper without the encouragement of regular attention has also shown an example in the techniques of establishment for early shelter. At the Scottish Horticultural Research Institute, on the north bank of the Tay, the network of shelterbelts started in 1953 afforded shelter after very few years and would inspire or reassure the most pessimistic who might have vaguely contemplated planting for protection.

Tree belts and hedges are not the only means of supplying shelter. Commercial horticulture covers a tremendous diversity of product, from cut flowers, vegetables, salads, seed, bulbs, annual and perennial plants, soft and hard fruits to ornamental and forest trees and shrubs. What suits one branch of the industry may be a disadvantage to another. Ground that moves round on rotation, from one crop to another, some more dependent on shelter than others, may not lend itself to too much sub-division by immovable, living barriers; portable screens may be more acceptable. On the other hand, where the product is more standardized, or where the producing stock itself is retained for some time, e.g. in orchards, permanent shelterbelts and hedges are better. These are management questions which have to be decided in their proper context.

Where permanent windbreaks are appropriate, pressure on space and the advantages of screens that can be controlled at a particular height, so as to avoid too much shelter and too little ventilation, usually subscribe to a hedge or single line of trees. In cases of severe exposure and where there is a danger of gaps occurring in the single row, more rows imply greater stability and, frequently, greater height. Even then, a width of 20 ft should prove adequate to accommodate large trees and an underwood for lower protection. Windswept areas, where wide strips may be required to achieve height, may be more suited to a series of lower hedges at closer intervals, which also prevent overshading and problems of root competition. Lath fences, evergreen *Veronica*, *Escallonia* and *Pittosporum* hedges, even strips of living bamboo, do this in the Scillies. The Cornish hedge, a wall or bank with hedge on top, shelters horticultural areas in the south-west; stone walls do the same in Mahon and Minorca; strips of rye serve as windbreaks for new vines in Hungary or onions in Michigan. They are all practical possibilities where taller windbreaks are difficult or undesirable; and also give earlier protection to more land. But a point in favour of height is the protection afforded by a tall belt on the east from the slanting rays of morning sun after frost.

Apart from considerations of root robbery, discussed in the previous chapters, the selection of trees and shrubs is limited by those which harbour pests and diseases. Here, again, the choice depends on the commercial crop and the hazards which threaten it. Many diseases are specific in that they affect only one particular plant or family, e.g. *Venturia inaequalis*, apple scab. For others, a wide range of species acts as hosts, e.g. *Botrytis cinerea*, which may occur on cereals, root and forage crops, vegetables, fruits, shrubs and trees, including hazel, horse chestnut and seedling conifers. Others require alternate hosts on which to pass the various stages of their complex life cycle, e.g. the black stem rust of cereals, which passes the aecidial stage on *Berberis vulgaris*. Furthermore, it is not always that the trees or shrubs play host to the disease itself but form some other link in the biological chain; in Holland planting of the popular shelterbelt species, *Prunus serotina*, declined when it was found to act as an alternate host to the aphid carrier of a virus disease affecting sugar beet.

For planting around Russian gardens and orchards, wild fruit trees like apple, pear, sloe, cherry, hawthorn and rowan and also false acacia, oak and hornbeam, which amongst others serve as sources for the spread of certain insect pests, are ruled out. Similarly, common buckthorn, barberry and juniper because they are intermediate hosts of rust fungi. In Britain, for fruit-growing areas, it is advisable to avoid members of the rosaceous order, thereby losing a considerable number of otherwise useful species. The bitter rot of apples, *Glomerella cingulata*, occurs also on privet; *Nectria galligena* causes canker of apple and pear and also of ash trees; *Phytophthora cactorum*, producing fruit rot in apples, has been recorded on ash, sycamore, larch, spruce and Scots pine; *Sclerotina laxa*, causing brown rot and blossom wilt in several fruiting trees, occurs also on whitebeam and bird cherry; *Stereum purpureum*, the widely distributed silver leaf of fruit trees, especially plums, includes amongst its other hosts sycamore, horse chestnut, birch, cedars, hazel, cotoneaster, hawthorn, broom, beech, laburnum, larch, pines, London plane, gean, laurels, mahaleb cherry, blackthorn, roses, rowan, lilac, elm, occasionally *Lonicera nitida*, and is common on dead branches of poplars.

The chance of spread in the soil by root contact of *Verticillium albo-atrum* and *V. dahliae*, which cause wilt of potato, pasture and forage crops, vegetables, hops, plums and strawberries, eliminates species like *Rubus*, privet and rose where their inclusion in windbreaks would be risky. In the Scillies and south-west England, *Rosellinia necatrix*, white root rot, has been found on elm and *Pittosporum* hedges, creating concern for fruit trees and soft fruits. In the same region *Tranzschelia pruni-spinosa* is common in second-year and perennial beds of anemones and may defoliate plums when these flowers are near. Five-needled pines, e.g. *Pinus strobus*, may also be ruled out when blackcurrants are there to supply the alternate host for *Cronartium ribicola*.

Many broadleaved species provide a habitat for winter moth larvae from which they can spread to fruit trees. Similarly, myrobalan plum, useful for hedges in some areas, can like hawthorn be attacked by the magpie moth and create anxiety amongst gooseberry and blackcurrant growers.

It is in the fruit-producing districts that most caution is needed in selecting shelter species. In spite of restrictions a fair choice remains. Quick-growing poplars are important for single-row windbreaks, provided there is sufficient soil moisture to satisfy their thirst without depriving crops. In Holland, Lombardy poplar and alder, closely planted in the same row, have successfully sheltered young orchards. Common alder (*Alnus glutinosa*) is popular because it roots deeply in an underlying, wet subsoil and does not compete with nearby crops to the same extent as many other species. Willows and lime can be used likewise without much risk. Lombardy poplar must be discredited, however, in some market garden areas where the migratory aphid, *Pemphigus bursarius*, occurs on this poplar particularly and then flies to the roots of various *Compositae* before returning to poplar in autumn. It may constitute a serious menace to lettuce crops, for example. Some of the Black Italian hybrids, e.g. *Populus serotina*, are resistant. Amongst conifers, Lawson cypress, thuja, *Cupressocyparis leylandii* are suitable and Monterey cypress for milder regions. Not all species which support fungal diseases that are potential dangers to fruit trees are always eliminated entirely; satisfactory orchard shelterbelts have incorporated ash, birch, beech, elm, hornbeam, sycamore, Swedish whitebeam, Scots and Corsican pine, Sitka and Norway spruce, without apparent ill effects on the fruit. Serious attacks are often localized and where there is no great concentration of market gardening less attention need be paid to the restrictions. Spraying with fungicides and insecticides can also remove the danger.

Orchards require wind protection during winter when buds may suffer, through spring when blossom is setting fruit, to autumn when the crop is maturing. Complete calm is not wanted, merely a barrier to break the wind's force, adequate ventilation being essential. Stagnation of air within the orchard, with consequent inability of crowns to dry out after rain, must be avoided. Shelterbelts should therefore allow plenty of air to filter through near the ground once young fruit trees are established because it is the crowns which need protection. Although studies in Holland have suggested that orchard windbreaks can usefully be planted as close as 6 'heights' for apples and 4 for pears, i.e. 15-ft windbreaks at 30 and 20 yards apart, respectively, this is not usual practice. An interval of 20–25 'heights' is more common, i.e. 100–125 yards for screens 15 ft high, since orchard trees afford mutual protection to one another, in addition to that provided by a windbreak. Also, even a single row of trees can be reckoned on occupying a strip of land 6 to 10 ft wide.

Multiple-row windbreaks around orchards should never be thickly planted. If a shrub row occupies the windward or leeward side, something should be selected which either grows loosely or can be coppiced at intervals to prevent too dense an underwood. For the remainder of the belt, other things being equal, preference should be given to a long-living species or one which will allow the introduction of another tree without the necessity for large gaps. The main species should therefore be a light-demander; if very fast-growing, and perhaps comparatively short-lived, it needs a shade-bearer alongside that will develop without being greatly suppressed.

Market gardens and nurseries have the same requirements as gardens. Restrictions on species are generally fewer than is the case with orchards, though some may be important. Information and advice concerning garden windbreaks given in the previous chapter will apply here, although in commercial enterprises utility and cheapness count more than amenity. The amenity aspect should not be overlooked, however, in nurseries dealing in flowering plants from alpines to ornamental trees; display is then an important selling factor. Shelter for low crops is the general need, not as with orchards. Ventilation is still important but the fairly free flow of air below recommended for orchards is not required. Moderately penetrable belts, even if apparently dense towards the bottom, will not impede a proper circulation but the dense belt can do this and should be avoided on frosty sites especially.

Spacing between belts can be adjusted to meet particular requirements; for sensitive crops and cut flowers, 10 'heights' apart may be regarded as the optimum but in most cases an interval of 20 'heights' suffices. In Carlisle Corporation nurseries, Manchester poplar (*Populus nigra betulifolia*) windbreaks, cut back to 10 ft and about 200 ft apart, afford a sheltered site for rearing various small shrubs. Closer spacings impose heavy demands on ground without correspondingly greater benefits.

Where the risk of disease limits the choice of species, there is something to be said for using as windbreaks the same material as the permanent crop. This may be possible in few cases. On some tea estates in Nyasaland, it has been suggested that rows at intervals should be left to grow on without the customary pruning to the 'picking table' level, as an alternative to introducing special shelter trees. Orchards could presumably be treated on similar lines. On the other hand, a large area broken up by windbreaks of a completely different species may serve to halt the spread of a particular insect or disease. Furthermore, it would be dangerous to use the typical species when the producing crop consists of specially bred varieties that may not be resistant to pests harboured by the type.

There is an obvious advantage in employing windbreak species that are also productive. Many trees and shrubs produce a saleable sideline, such as the foliage of holly and cypresses. Some Lincolnshire, Norfolk and Cambridgeshire bulb growers have used cultivated blackberries on strained wires between concrete or wooden posts to protect low crops in spring. They pay for their cost, their space and pruning with the value of the blackberry crop and in the war years earned more than the bulbs. In their leafless state they offer valuable winter protection and provide a denser barrier in summer. On 7-ft posts 12 ft apart, with 4–4½ ft above ground, carrying stout wires every 8 or 9 in. or alternatively chain-link netting, such windbreaks should have 4 ft clear each side for picking and pruning. Planted with 'Himalayan Giant' blackberries 12 ft apart, pruned hard each winter to remove branches that have fruited, or with the slower growing 'King's Acre' variety at 8 ft, which takes longer to make a windbreak, shelter can readily be combined with profit.

WINDBREAKS FOR ROAD AND RAILWAY

Roadside planting is only occasionally a matter of protection against wind and snow. Amenity considerations are the dominant factor governing sites selected for planting, the arrangement and choice of species. However, in recent years, attention to the aesthetics of modern highway design has shown that roadside planting is not merely adding a few trimmings to a straightforward piece of engineering. In spite of careful adherence to the best engineering standards of curvature and gradient, the finished alignment, due perhaps to an unfortunate relationship of horizontal and vertical curves, may be out of harmony with the surroundings and even present a distorted impression to the driver. Efficient road design should combine the skills of the engineer with those of the landscape architect to present a continuously unfolding ribbon of road, aesthetically satisfying and fraught with fewer hazards because the driver can anticipate accurately what the next stretch of road will reveal. In this, planting can play an important part and may, on occasion, be combined with supplying shelter in the odd places where it could be of value.

Highland roads in particular have their trouble spots where strong gusts are channelled between the hills. Few are really amenable to planting and costs would in any case be out of proportion to the risk to road users. On motorways the position is different: they over-ride undulations in the countryside that are followed by the wind and consequently normal wind conditions are accentuated in one place, subdued in another. Cars emerging from cuttings or under fly-over bridges are frequently caught by a disconcerting gust on windy days. These are places which can be improved by planting. An elongated clump or one or two lines of trees, which make a more gradual transition from the calm of a cutting or lee of a bridge to open wind conditions, will check the furious swirl of the wind-stream round the sides of these obstacles. These would be small plantings and inexpensive, requiring no fencing and the simplest possible planting stock. Their structure should aim at sieving the concentrated flow of the wind, not deflecting it elsewhere. Ideally, clumps should be thicker next to the wall of a cutting or bank of a bridge, thinning out further away. Young pole stands of alder, ash, beech, birch, maple, pine, spruce or sycamore, probably with a loose shrub layer below or on the outside to fill in when trees lose their lower branches, would achieve the object. Preference should be given to indigenous species appropriate to the surrounding countryside and, in the case of planting near bridges, to something unlikely to detract from their architectural merit.

Such plantings should not seriously increase the snow problem; cross-wind cuttings are always liable to pack with drifts. Snow is deposited wherever there is a local drop in the wind and any road in undulating country can expect difficult spots. Only on flat terrain with roads raised above the general level and free of bordering hedges can this problem be eliminated entirely. Many Canadian prairie highways achieve this but others are not without their stretches of snow-fence where called for by the topography. The only way of preparing for trouble is to collect the snow before it reaches the road.

In most cases, the superior claim of the snow-fence over planting is unchallenged. It is standardized, gives immediate protection and raises few objections from occupiers of land on which fences are erected for the winter. Materials are not always cheap but costs of annual erection and dismantling exceed interest charges and depreciation. Consequently, some North American authorities advocate a wider use of snow-collecting hedges, set back from the road, as being cheaper in the long run. In Manitoba, assuming a 25-year life for *Caragana* hedges, the cost per mile per year was recently estimated at 100 dollars, compared with 225 dollars for the usual slatted snow-fence with an average life of 20 years. No rental charges for the land occupied by hedges are presumably involved, farmers deriving

31 *Ten-year-old, four-row shelterbelt at the Scottish Horticultural Research Institute, composed of beech, sycamore, birch, Sitka spruce and Scots and Corsican pines*

32 *Mixed shelterbelt in Midlothian, composed chiefly of Scots pine and birch and providing good shelter. Younger trees on left planted to fill a gap and to provide continuity as the older trees mature*

33 *Small ash group planted in a matrix of larch and pine. Strong conifer branches (top right) require regular pruning to avoid suppression in the early stages of the broadleaved trees*

34 *Shelterbelt of oak and sycamore on heavy clay. An understorey is necessary to close the space below the crowns. A closer planting initially, possibly using a 'nurse' species, e.g. Scots pine, would have been advisable*

some shelter from them for the rest of the year, together with the moisture from the collected snow which is not unimportant. As laid out in some mid-Western states and prairie provinces, these hedges leave sizeable strips of land, perhaps 100 yards wide, between hedge and road to be cropped and cultivated without inconvenience. In Britain, the greater sub-division of land and the diversity of the farming pattern would not support such an arrangement except on unfenced hill roads, where the need to fence against sheep and deer would rule out hedge planting.

Wider belts have, however, been planted in places where snow is a regular problem: the Soutra Hill road south of Edinburgh is an example. The chief advantage of tree windbreaks lies in the extra height which may be secured as compared with snow-fences. Obviously this is important where the topography is very involved. Palisades of sleepers border many Highland railway lines and so long as they last may prove effective but to replace them or increase their number would be a major undertaking and more expensive than plantations which might also be productive. Regrettably, any major extension of these practices (the Soutra planting is considered experimental) would likely be obstructed by administrative and financial difficulties, no doubt serious in Britain though overcome in Germany, for example. If a shelterbelt can safeguard a section of road and at the same time shelter livestock on adjacent land some means of sharing costs would seem reasonable. Similarly for plantations alongside railways, which might have to pay a higher share owing to the need for species with low combustibility; fortunately, most hardwoods and Japanese larch fulfil this requirement and would, amongst them, supply the majority of sites.

Where it is possible to use planted snow-breaks, bearing in mind that a 4-ft snow-fence can be lost in the topography and that the cost of taller, artificial barriers rises very sharply, it is a mistake to create a tight, windward margin. If the wind is deflected over the trees, a considerable amount of snow will be transported farther down-wind. The windbreak structure should filter the wind and, in doing so, trap the snow. At 100 ft or so from road or railway there is little risk of blockage. With tallish hedges, fairly open to wind, drifting rarely extends more than 60 ft; the bulk of the snow invariably lodges within 40 ft on the leeward side. Shelterbelts with an underwood collect the snow within, at most, 100 ft on the lee side, usually much less. Wider plantations, because of restricted access for the wind when fully stocked with trees, should be capable of absorbing a good deal of snow in the interior, chiefly on the windward edge; this part could reasonably be more open to penetration. But it is not sufficient to have tall trees spaced wide apart; low cover, as provided by covert shrubs, is necessary to initiate drifting and even grass round the bottom of a netting fence can serve this purpose.

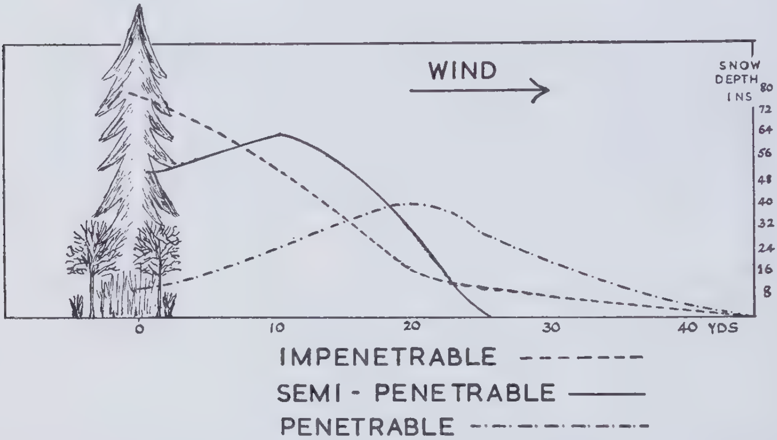


Fig. 22 Snow drift patterns adjacent to windbreaks of different penetrability, Czechoslovakia (after Luncz).

Care should be exercised to avoid snow damage to young plantation trees. Pines particularly suffer in this respect. Young branches are brittle and easily broken; wet snow on older crowns can cause serious injury. An old Canadian protective measure was to plant an additional row some distance windward of the main plantation, so as to collect the heaviest deposits of

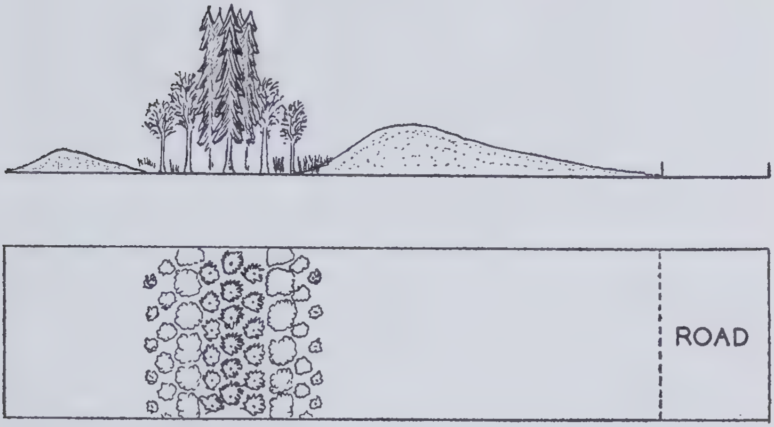


Fig. 23 *Windbreak designed to trap snow adjacent to a road, Czechoslovakia (after Luncz).*

snow. Practical considerations have out-dated this practice; it is better to take precautions when selecting species and hardwoods, larch and spruce can be mixed with, or replace, the pines where the site is appropriate. Spruces and silver firs, planted pure, form too dense a barrier when young but the quick-growing Sitka spruce, preferably mixed with Scots or lodgepole pine in strips no more than a chain wide, is invaluable for early results on much hill ground. Its efficiency improves as it passes out of the dense thicket stage which is relatively short-lived. Species such as alder and aspen with their habit of suckering, birch and sallow are also very useful for snow-breaks in hilly districts. For the most difficult sites at higher elevations, mountain pine forms a spreading windward margin, protecting taller trees behind, and collects the snow if not allowed to develop too thickly.

Drifts piling up against plantation fences allow hares to enter. Clearing the drifts under adverse weather conditions and at great expense is usually out of the question. In narrow belts, thinning out or removing the underwood cuts down the risk and all that this involves is that the leeward drifts extend farther from the trees. Typically, drifts behind permeable belts are long and shallow and start slightly to leeward of the trees; behind dense structures the drifts are short and deep and start at the leeward edge. With wide and dense plantations, little can be done to alleviate the hare problem beyond thinning out the windward section to attract much of the snow and keep the windward fence, at least, fairly clear.

Apart from the question of snow drifting and localized problems near cuttings and embankments, wind conditions on roads rarely call for control. Nevertheless, shelter becomes involved wherever planting is undertaken or existing woodland is retained for purposes of amenity or more efficient road design. The planting of centre strips on dual carriageways to reduce dazzle from oncoming headlights, or the use of roadside trees, can alter the climate and appearance of the road surface appreciably. This is not always for the better: the shelter afforded by a dense row of shrubbery or taller trees may delay the drying-out of the road after rain, whilst a still pool of air on frosty nights may increase the risk of ice. Shading from large roadside trees may mean slower thawing of hard-packed snow when open stretches are quite clear. In addition to such changes in the nature of the surface, shading and shelter may introduce sudden changes in colour which can occasionally distract the driver. Keeping central shrub rows open so that they do not form a continuous, thick hedge ensures maximum ventilation and removes most of the disadvantages. Similarly, roadside trees, set far back from the highway, create no problem of overshading or delayed drying.

Overshading is not always undesirable; on minor roads it is often a very attractive feature but on high-speed motorways it is out of place. For the latter, the formal type of avenue planting should also be avoided. Requirements are different from those obtaining when Napoleon lined French roads with avenues to screen his marching armies. For fast motorists, evenly spaced trees at roadsides are bad for road safety and should be confined to minor roads or the outskirts of cities. In open country a more informal arrangement of clumps or masses of woodland that merge with the landscape is more appropriate. If road

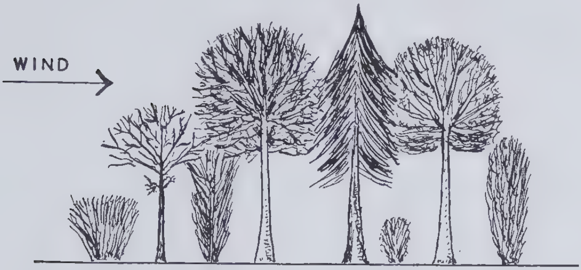


Fig. 24 *Windbreaks for collecting snow should have shrubs to initiate drifting on either the windward or leeward sides as appropriate.*

surfaces are to be kept as dry as possible, planting of clumps or strips should adhere to the east or north sides of the road; this is also preferable from the point of view of snow accumulation, once a margin has been allowed to accommodate the drifts. In districts prone to heavy falls of snow, windbreaks parallel to roads should rarely be less than 75–100 ft from the kerb; belts lying obliquely to the road direction may come nearer if they deflect the wind sufficiently to sweep the snow across the road but this can never be guaranteed and a single tail drift lodging on the road surface can constitute a major problem.

Any mixed planting on major roads must avoid intricate and fussy arrangements that might worry or distract motorists. Broad masses of a single species or very simple mixtures are preferable to a gardener's collection. Ornamental species, permissible within the civilized atmosphere of city approaches, should be used cautiously in open country. Native species, in the form of hedgerows, groups, clumps or woodland blocks that follow the local pattern, can provide optical guidance to drivers and relieve the monotony of highways without interrupting the general appearance of the landscape. Exotic forest trees, especially conifers, suit certain surroundings but are at odds with others and are best reserved for upland districts in the north and west. These are points which the landscape architect will observe.

The road engineer may be more concerned with other tree characteristics: root spread, for instance, with its attendant threat to drains and road surfaces. Trees near roadworks should not have far-ranging roots and poplars are particularly undesirable. Storm-firmness is also important, which again suggests deep-rooted species like ash, wych and Guernsey or Jersey elms, hornbeam, horse chestnut, lime, maple, oak, pine, sycamore amongst larger trees; alder, birch, wild cherry, crab, hawthorn, rowan, whitebeam and willows amongst smaller trees. All these are fairly resistant to pollution caused by exhaust gases, which will become more serious as road traffic increases. Some of the barberries, *Cotoneaster*, flowering currant, dogwood, elder, holly, laurels, myrobalan, *Rhododendron ponticum*, *Veronica brachysiphon* and yew are amongst the most useful shrubs for highway planting, withstanding polluted atmospheres and requiring the minimum amount of pruning. Other species suggested for urban and seaside planting offer a further selection, but preference should always be given to familiar varieties cheap to purchase and easy of establishment.

9 Planting for Shelter on the Farm

Shelterbelts afford most benefit when located and designed to suit not only wind direction and topography but also the farming pattern. Some parts of a farm need shelter more than others and the demand is often seasonal. Spring grass may require encouragement or lambing fields protection against chill winds. Providing the shelter when needs are urgent, when, for example, new crops are at critical stages, soils are prone to blow or pastures are heavily stocked, is a management aspect. Shelterbelts that tide farmers over difficult periods or offer a more balanced basis for intensive working of the farm may be worth more than first impressions would appear to indicate. Concentrating on key areas to make for greater efficiency on the farm as a whole is sounder practice than scattering belts haphazardly over the land.

This calls for a knowledge of the worst winds and the quarters where they originate. Prevailing winds, which may not be the most harassing nor prevail half the time, are mostly westerly to south-westerly, whereas the coldest are from the north and east. One belt lying north-west to south-east can check both in season and probably serve a dual purpose if winter crops or lambing quarters are on its west side and summer crops or pasture on the east. This is a typical point which merits consideration when planning for shelter. Matters to be borne in mind and planning principles to be followed assume different degrees of importance according to the prevailing farming pattern. Lowland farms on the one hand, upland and hill farms on the other, all have common problems but also their particular ones. On balance, it is convenient to consider the two separately.

LOWLAND FARM SHELTERBELTS

Orientation. Belts sited directly across the harmful wind give maximum protection but existing field boundaries usually control the direction. For practical purposes, however, there is little difference in the average shelter available when winds vary within 45° of the normal, i.e. between north-west and south-west when the mean direction is westerly. Most winds fluctuate about a mean direction, veering and backing with successive gusts and lulls, so that some latitude in choosing the actual line of a belt is permissible. Inevitably, the distance over which velocity is reduced becomes shorter when the wind strikes a shelterbelt obliquely; to cater for these deviations calls for an adjustment of the length of the belt.

Length. For full advantage of distance protection against a cross-wind, a shelterbelt needs to be roughly 12 'heights' long, i.e. 120 yards for a belt 30 ft high. Because the leeward sheltered area assumes the shape of a blunted triangle, the maximum shelter effect in the centre is not achieved until the length/height ratio is of this order. Against cross-winds which deviate as noted above, the ratio should be at least 24, more if possible. Even with winds constantly normal to a shelterbelt, the area sheltered increases sharply with increasing length of belt until the latter is about 12 times the height and does not increase linearly with length until this is 18–20 'heights'. Thus, length plays an important part in regulating efficiency.

Layout. Care in planning can achieve economies on valuable land. Where copses, game coverts and scattered clumps of trees exist, their incorporation in an overall plan gains additional shelter at no extra cost. Standing isolated in the landscape

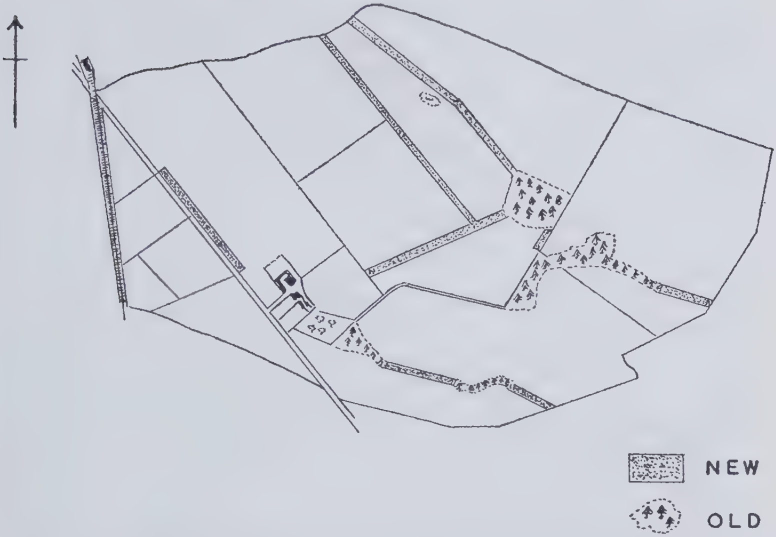


Fig. 25 Linking isolated blocks and clumps by new shelterbelts increases the overall shelter.

they have little beneficial influence on winds; linked by a belt or two they increase the protected area appreciably. Hedgerow trees, although they 'roughen' the landscape and exert some frictional drag on the wind, are often regarded as a nuisance because of eddies that roll around and under the crowns and flatten cereal crops behind. Yet, a hedgerow forms an excellent backbone or windward border for a new belt and the extra height afforded is a definite advantage in the early years. Again, unused or less productive areas, embankments, river banks, old cart tracks and patches of stony ground or poor soil may be drawn on to lighten the loss of good land.

Further economies can be obtained indirectly. If major trees in belts bordering roadways are confined to the side near the road root spread into cultivated ground and shading can be reduced. Along streams, planting the tallest trees on the south bank throws shadows over the water and not over crops. Using existing ditches for a shelterbelt boundary also restricts root ranging.

If a choice is possible, entrances to fields are best made through belts parallel to the prevailing wind. Where they have to pass through cross-wind belts, the gap should be cut obliquely unless there is a danger of the entrance becoming blocked with snow at an awkward time; in such cases openings running straight through are preferable. Gaps cause draughts but unless they are wide the wind fans out very little after passing through and the loss of shelter is small.

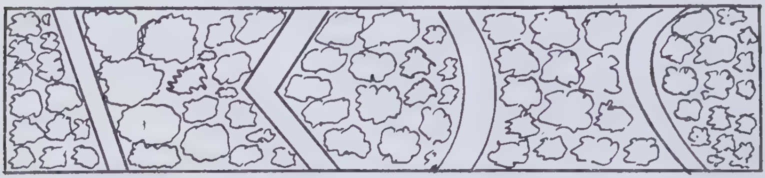


Fig. 26 Ways through cross-wind belts may be angled or curved to keep out the wind but are liable to fill with drifted snow.

Sharp changes in the line of a belt, except at field corners, should be avoided. They obstruct efficient cultivation and are vulnerable to storm damage. Furrows ploughed parallel to shelterbelts, if the latter run in only one direction, avoid hindrance to tractors turning and damage to unfenced belts. To avoid Canadian farmers' objections to the close spacing necessary between low windbreaks on extensive arable land, alternate strips are frequently cut short at the ends. Two 'fields' can then be worked as one around a central windbreak. This system might be worth a trial as an alternative to removing all hedges where they restrict mechanical working.

Damaging winds can spring from any direction and an exceptional wind deflected along the side of a belt occasionally causes damage to grain crops in particular. Secondary belts at right angles to the main strips overcome this difficulty. Many old shelterbelt systems were laid out in a 'grid' or 'mesh-work' arrangement, enclosing fields often 350–450 yards across. Distances of this order appear to be a reasonable interval between parallel belts. An interval of about 26 'heights' ensures that the unobstructed wind velocity is not regained anywhere in between the belts but, since height increases until maturity is reached, there can be no 'optimum' interval covering the whole of a shelterbelt's development. Unless the need for shelter is exceptional and potential returns unusually high, as can be the case in horticultural enterprises, and warrant intermediate, temporary windbreaks to be removed once the main belts supply adequate protection, it is better to arrange the distance apart on the basis of the expected maximum height of the trees.

On the German low country of the Cologne and Munster

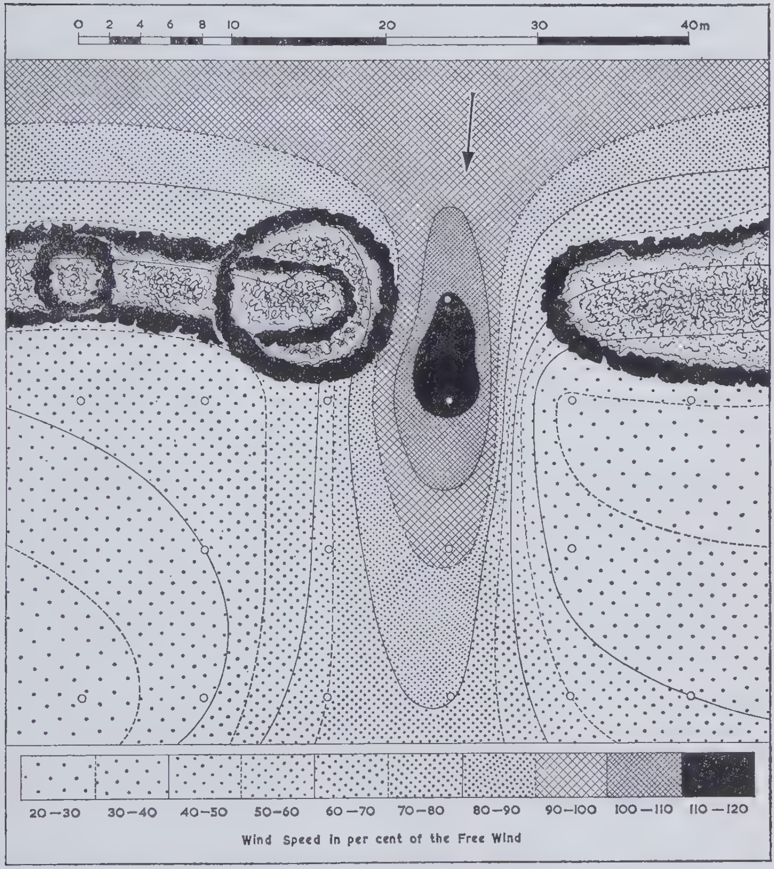


Fig. 27 *Plan of wind conditions near a shelterbelt, showing acceleration of the wind caused by a gap (after Nägeli).*

plain, with average annual wind speeds of 6–8 m.p.h., principal belts are 30 'heights' apart with secondary belts, at right angles, up to 50–60 'heights' apart. With belts 10 m. (33 ft) in height, the enclosures are approximately 37½ to 45 acres in area. This is sufficient to effect a general improvement in water economy and micro-climate, giving roughly a 20 per cent moderation of growing season winds. For more unfavourable climatic conditions or specially sensitive crops, cross-wind belts are slightly closer but it is recommended that fields should never be less than 7½ acres and are more often around 30 acres.

Control of soil erosion may necessitate closer intervals since, for complete success, it calls for total elimination of all winds exceeding the soil's critical or 'threshold' value which decides liability to blow. In the Senne district of Germany, reducing the wind level by 30 per cent eliminated only 85 per cent of all winds over 16 m.p.h. Placing parallel belts as close as 15 'heights' improved the position but complete control over critical wind speeds was achieved only when the interval was reduced to 10 'heights' and the overall wind level was reduced by 45 per cent. Elaborate planting networks are profitable only when land is intensively cropped and wind erosion of soil cannot be controlled by other cultural methods, such as better methods of cultivation conducive to clod formation, abandoning the use of rollers, adjustment of sowing dates to avoid the dangerous blowing period, strip cropping, marling and stubble mulching.

Proportions of land which can be transferred to trees in the interests of shelter depend on the exposure and the level of production to be maintained. A common view expressed in old literature was that 8½ acres of shelterbelts were desirable on a 160-acre farm, involving planting about 5 per cent of the total area. For fertile farmland this would be excessive; Germany currently favours 1 per cent for good lowland areas. It is not only a question of land occupied by trees but also the marginal strips which, in certain climates or seasons, are put partially or completely out of production through shading, root competition and other edge effects. In prairie belts, where it is customary to fallow a rod-wide strip on either side, the total loss of ground may be three times that taken up by planting. In Britain the problem is less serious but often arises. To minimize these edge effects, bordering species which do not overhang, interfere with field drains or impose heavy demands on adjacent ground are advised.

Width. There can be no hard and fast rules about optimum widths. These vary according to the density and disposition of the trees and shrubs planted. Manipulation of the design and planting pattern can frequently save useful space. On land which will yield a better return from agriculture than from forestry, the limiting width should be that on which it is possible to establish a belt of suitable height and penetrability. This will depend on site factors and exposure but should rarely require to exceed 30 ft in a reasonably good, arable farming district or 50 ft at the outside.

Permeability. Arable shelterbelts need to filter and break up the wind stream without provoking damaging eddies because both quality and extent of shelter matter. The creation of very dense structures can be detrimental to nearby crops; what is wanted is a 'curtain' of foliage and branches flecked all the way up by patches of light that penetrate from the other side. Ideally, one should be able to detect movement of livestock and tractors on the opposite side of a shelterbelt but not be in a position to make out without difficulty, and certainly not to see in complete outline, the object that is moving. Uniform penetrability over the whole height of a belt is usually favoured, but in practice there is a tendency towards having the bottom part denser than the top. To compensate for thickness in the bottom and, consequently, the higher proportion of wind diverted upwards, it is advisable for the upper section to be correspondingly more penetrable so as to comb out the turbulence that might otherwise be created. In the conventional, American, 'pitched-roof' construction of windbreak the central core of cottonwoods, protruding well above the other species, does this, making up for what is lost aerodynamically due to the cross-sectional shape deflecting most of the wind stream over the top.

Profile. An irregular canopy level in a shelterbelt, like the pointed tops of paling fences, is more effective in breaking up the deflected portion of the air stream than a uniform upper edge. A mixture of species is essential for this. The recent Canadian practice of planting taller-growing trees at intervals in *Caragana* windbreaks should achieve the desired pattern, besides affording extra height, recalling in principle the 'Cardigan bank' in which a free-growing hawthorn hedge stands on a high earth mound. In Germany, wider windbreaks also are planned to produce an uneven profile.

Single-row Windbreaks. A single line of trees or shrubs, or a mixture of both, may provide adequate shelter or be all that can be entertained. The choice of plants is restricted if height is important and one is at the same time to avoid a species of spreading habit which can soon occupy as much space as two or three rows. One-row strips can be difficult to maintain and, under exacting conditions, hard to establish; yet, there are many examples. Single lines of the shrubby, tenacious *Caragana arborescens* stretch for miles in Saskatchewan; hedgerows of Sitka and white spruce abound on Danish heaths; cypresses and eucalypts are used extensively in Mediterranean countries and poplars throughout the temperate zones.

Poplars are unquestionably the most prominent in this field. On good sites rapid growth means early shelter but since even narrow-crowned forms need space for development, being intensely light-demanding, stems soon become open to the wind. Pruning to give knot-free butt logs, worthwhile wherever poplars grow well, accentuates the bareness beneath the crowns. All but the fastigiate varieties should be supplemented with an underwood to maintain effective shelter.

Alder and willow, coppiced as necessary, can fill the spaces below the poplars but not always very tidily; willows, especially, spread laterally to get light. Sitka and Norway spruce, Lawson

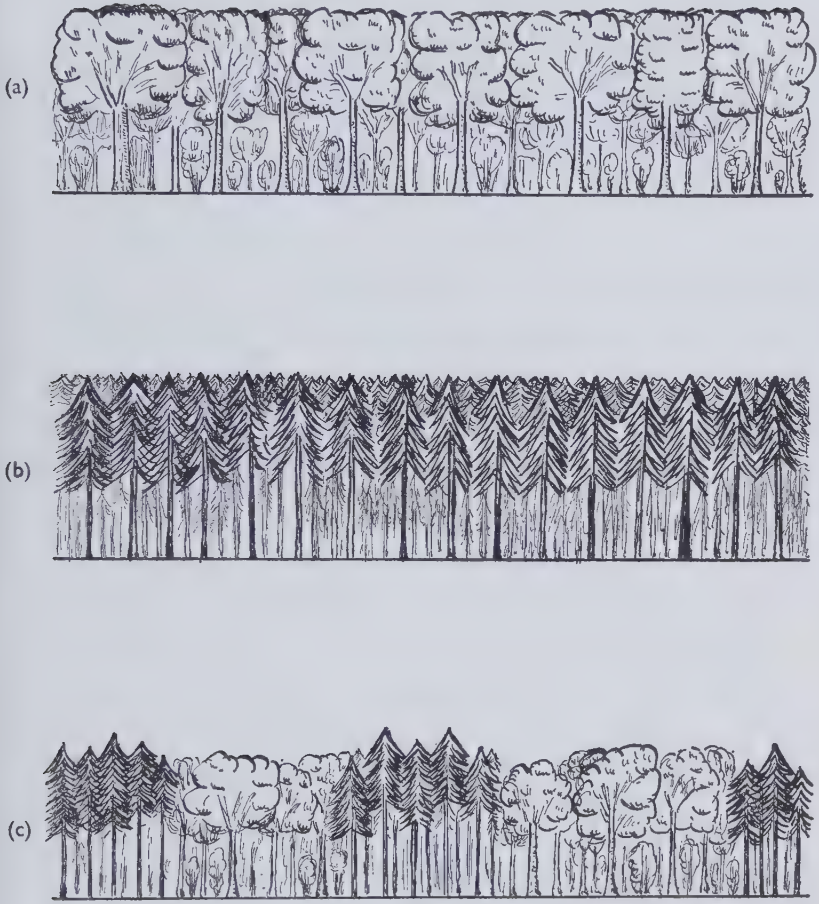


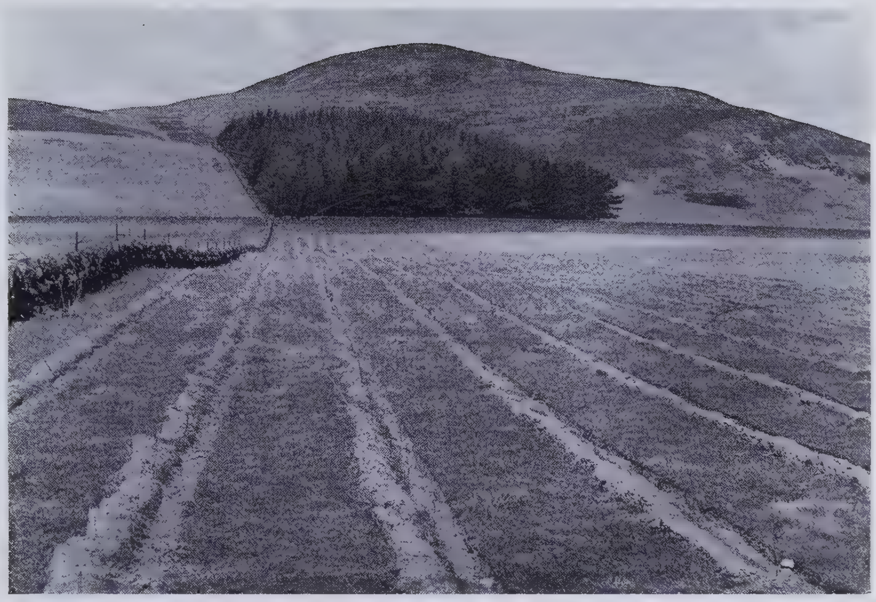
Fig. 28 *An irregular profile is more effective in reducing eddying* (*c*), *than more uniform structures* (*a*) *and* (*b*).

cypress and hemlock are also suitable for interplanting poplars at 18 ft spacing and upwards. Many shrubs succeed but few grow tall enough to meet the need as the poplars get into their stride. If used, some taller species should be added: lime, for example, is a good choice; or hornbeam, not all of which need be allowed free height growth, the rest being cut back to give a new crop of stool shoots for low cover. But much depends upon the strain of poplars selected.

One of the most promising poplars for single-row planting is the hybrid *P. tacamahaca* × *trichocarpa* '32', which has grown up to 12 ft in its first year from stools in the Mackeson-Sandbach nurseries in Wales. Being extremely narrow crowned and fairly light of foliage, it is best planted at 6–8 ft spacing initially, when its spectacular growth will soon form a fine windbreak. Similar in many respects but with a somewhat denser and broader crown and a little less vigorous, there is *P. tacamahaca* × *trichocarpa* '37'. Canker-free strains of *P. trichocarpa* are worth considering for their vigour and more bushy habit, provided exposure is not too severe, but like the hybrid black poplars such as *P. robusta* and *P. laevigiata*, they need plenty of space and are unable to form an effective wind barrier by themselves. These should not be planted closer than 18 ft and even then need to be thinned once the broad crowns begin to close up. Supplementary species should be interplanted amongst the poplars from the beginning; establishment later on may prove difficult. A 3-ft spacing for the intermediate plants is suggested since it is easier to remove any surplus than to add more.

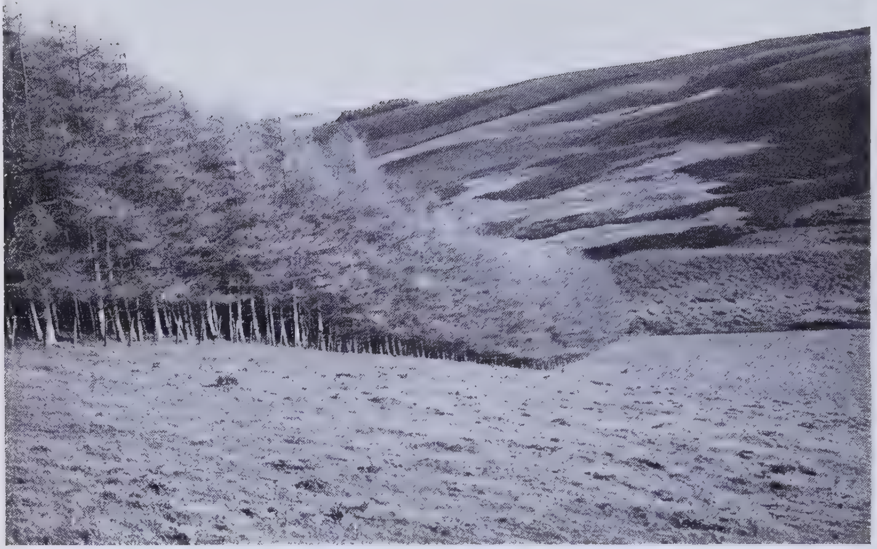
No other broadleaved species can supply a one-row windbreak with the same speed and satisfaction. Again, most have spreading crowns so that the advantage of the single row is lost. Those with narrower form, such as lime and pyramidal varieties of elm, beech and hornbeam, are too expensive for more than restricted use in farm windbreaks. Hawthorn and Swedish whitebeam make shorter hedgerows and can be side-trimmed as required; lines of alder, hazel, chestnut and willows, generally coppiced at intervals, are frequently seen dividing fields. But, to extend their shelter effect, it is better to add taller-growing trees like ash, elm, sycamore and maple at intervals of from 6 to 15 ft along such lines.

Many conifers in single rows provide good shelter in their early years. *Thuja* and cypresses are hardly farm species, except for the interior of wider belts, many farmers distrusting their foliage from the point of view of stock, but pines and spruces chosen according to site are useful species. Norway spruce suffers from blast and may be slow to start; white spruce,

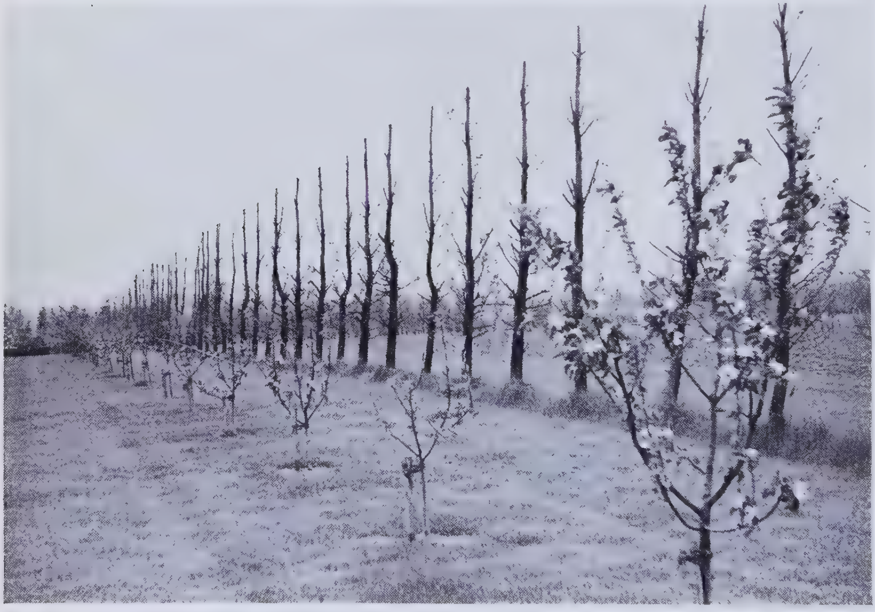


35 *Hill shelter block being extended by means of a strip one chain wide to check valley winds and improve the overall shelter. The shallow ploughing reduces grass competition and aids the establishment of young trees*

36 *Compact shelter block of Scots pine for stock shelter on grazing land in Northumberland*



37 *Larch shelterbelts afford useful shelter when young but eventually become open and draughty below*



38 *Poplars, 6 ft apart, pruned hard to reduce competition and maintain permeability during the summer*

successful in Denmark, has not displayed any superiority under our conditions; but the sturdy Sitka spruce is capable of forming a sound one-row strip. After the first flush of youth, probably in twenty or thirty years, it is apt to suffer check and start to deteriorate, losing also its lower cover, especially where moisture is inadequate. This may not constitute a serious disadvantage if one is prepared to accept the fact that single rows of Sitka spruce, like poplars, are comparatively short-lived. Scots and Corsican pines make a less dense windbreak but often satisfactory in the first 15–20 years. Afterwards, they need to be supplemented by interplanting partial shade-bearers in the line, e.g. beech and a choice of shrubs.

Multiple-row Shelterbelts. Inevitably, single rows lack flexibility; every tree or shrub becomes of major importance and gaps appear as individuals fail or lose their lower branches. In the end, one must remove the old row or start again elsewhere, which means taking in more land. Multiple-row belts impose fewer restrictions and allow shelter to be maintained indefinitely. They are not necessarily wasteful of land; even single rows can be reckoned on using a 10-ft strip and broad-crowned trees overhang beyond this. Yet, successive rows at 5 ft apart, say, take up only another 5 ft per row. Thus, strips of 15, 20, 25 and 30 ft support 2, 3, 4 and 5 rows, respectively, and with three rows and more the whole structure can be contained easily within this width, without encroachment on productive area, above ground at least. Overhanging is checked by keeping broad crowns to centre rows with shrubs or small trees on the margins.

Narrow belts of few rows filter the wind effectively, deflecting little of the wind over the tree-tops. This is the essential function of a windbreak; the idea of deflecting the wind upwards and over the top, which has crept into much advisory literature, supplanting the sounder advice of a century ago, is fundamentally wrong. In situations of severe exposure vegetation is moulded naturally into aerodynamic shapes which minimize resistance to the wind. To copy these intentionally produces little interruption to the wind and, hence, little shelter. In the American 'pitched roof' belts, so long as the cottonwood core remains tall and vigorous the wind stream is broken up fairly efficiently; once it fails, as has happened in many shelterbelts in South Dakota and Nebraska after 18–25 years, the range of protection can be suddenly reduced by a third or more. It is better, therefore, to aim for structures with reasonably vertical sides rather than plan for gradually sloping profiles when viewed end-on. When smaller species are kept to one or two outside rows, a sloping face does not develop. On exposed farms, however, a further safeguard is to plant the hardiest, tallest trees as near the windward edge as possible.

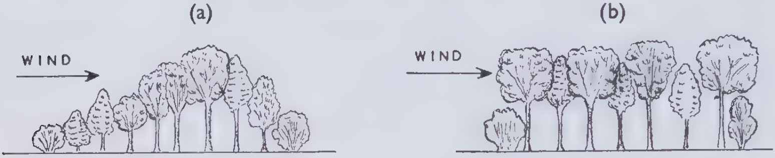


Fig. 29 Belts with a 'pitched-roof' cross section (a), are less effective in halting winds than belts with more or less vertical edges (b).

As with all shelterbelts, success depends on choosing a suitable composition. Four important points that should govern the choice of tree species are:

(i) Obtaining height in the shelterbelt as quickly as possible.

(ii) Providing for low shelter, necessary when the main trees begin to open out near the ground.

(iii) Stabilizing the shelterbelt that will be exposed to high winds.

(iv) Planning for permanence.

A fifth point might be added in the case of shelterbelts destined to supply some timber: choosing species to yield marketable produce for which there is a local demand.

Quick height growth is important because the area sheltered by a windbreak depends primarily upon height and it is economically desirable to achieve this as soon as possible. Fast-growing species with a relatively short life may be necessary for this, which accounts for the preponderance of poplars in

Continental and American shelterbelts. In one district of Switzerland poplars are planted very wide apart so as to allow the subsequent introduction of more permanent trees, though at the cost of losing some early shelter benefits until the poplar crowns almost meet. Species used to give height must be very wind resistant and capable of pushing up into the wind with little checking or shaping; otherwise the wind soon controls height and the extent of protection.

Shelterbelts too open near the ground are past their best but the provision of an underwood avoids this. Russian writers lay considerable emphasis on the maintenance of a healthy shrub layer throughout their shelter plantations and a fairly recent American planting design makes use of a tree-shrub combination in every second row, with the trees 6 ft apart and shrubs at 2-ft in between. A shrub layer provides for low shelter, suppresses unwanted weeds and can help to build up a woodland soil. Understorey species which, though taller, can be coppiced periodically fulfil the same purpose. Hazel, chestnut, ash, oak, sycamore, alder, hornbeam, lime, birch and willow all send up shoots from the stool when cut back, although some are more tolerant of overhead shade than others. On parts of the Rhine plain narrow poplar belts are commonly filled up with an underwood of lime, false acacia, hornbeam and cherry, closely planted and cut back whenever the belt appears too dense for efficient wind abatement.

An alternative arrangement, perhaps more appropriate for cases where such an intimate mixing of species is not possible, is to provide the low cover on outside rows only, sometimes solely on the windward side of the belt. This is easily effected with suitable shrubs or by alternating trees and shrubs if extra height is wanted. Hawthorn and similar hedges are ideal, whether trimmed or allowed to grow up into thick bushes.

Where the selection of species follows the natural tree vegetation of the countryside, wind-firmness is usually ensured. Other considerations, however, may suggest less stable material. But in all cases where there is frequent exposure to high winds and gales the use of some tough, wind-firm trees, if only on the margins, is advisable. Trees on really exposed borders can be more widely spaced than elsewhere to allow adequate root-hold; but more space does not necessarily guarantee better anchorage in the soil. Anchoring roots are confined within a comparatively short radius from the stem and long feeder roots have little effect on stability. However, if adjacent root systems become interlocked, individual stability is weakened.

Paying adequate attention to good windward margins is half the battle when it comes to replacing trees in the interior. Few species prosper in draughty situations and in narrow, open belts the wind beneath the trees is even greater than it is away from the belt altogether. Shelter near the ground provides a totally different environment for the new plants. In addition, if shelterbelts are clear-felled, which is sometimes necessary, a permanent wind-firm margin not only facilitates replanting but also ensures that protection to adjoining ground is not removed completely. Many old estate shelterbelts were of conifers, protected by margins of beech and hawthorn; in some cases these margins have already survived two conifer rotations.

Ideally, shelterbelts should be permanent. But few new belts provide for continuity. Only half the allotted width need be planted initially, the second half not until midway through the accepted rotation, and so on. Or perhaps an adjacent strip can be annexed for planting before the original site is cleared and, possibly, reclaimed for grazing if not for arable purposes. Another method is for the shelterbelt to be heavily thinned and underplanted, a process which cannot be repeated indefinitely since underplanting involves shade-bearing species which cannot themselves be underplanted. None of these alternatives, however, is as good as a staggered system of removal and replacement of the trees. For this purpose, a mixture of species not all of which are due to attain maturity at the same time is recommended. Subsequently, the more mature and short-lived trees are gradually cut, leaving small groups which can then be restocked. If this procedure is started early on in the life of the shelterbelt (and not delayed until the structure begins to deteriorate), being repeated at regular intervals of a few years until the whole area has been treated, continuity of the shelter is ensured.

This uneven-aged pattern which results is a modification of what foresters call the selection system, common on the Continent but rare in Britain. Basically, it allows for trees of all ages and sizes to be distributed over the woodland area at the same time so that, as mature trees are cut, younger neighbours are there to take their place.

Nevertheless, shelterbelts of one species are the simplest to plan and plant. They are the rule for single-row windbreaks but for others play only a minor part in long-term shelter, except where a long-lived margin allows the interior to be thinned or felled quite independently. That this is so is confirmed by the low standard of efficiency displayed by most pure conifer belts over 30 years old and the problems they present as regards improvement. Mixed stands can be difficult to handle and maintain, since some species try to suppress others, but reasonable mixing of the species to provide for the requirements listed earlier should be encouraged.

Pure and Mixed Stands. Compared with uniform stands of one species, mixed associations with roots feeding at different depths and crowns assimilating carbon dioxide and absorbing radiative energy from the sun at more than one level make better use of a site and take better care of the soil. They are also less vulnerable to wind, fire, frost, drought and disease, because of the varying degrees of resistance of the species employed. One species may even help another to become established.

Mixtures need to observe a few simple silvicultural principles. For example, when a slow-growing species is mixed with another that grows rapidly it must be tolerant of shade cast by the taller of the two and soil and fertility conditions must be adequate for both. The former estate pattern of mixing Scots pine and Norway spruce by alternate rows, $3\frac{1}{2}$ ft or so apart, often led to suppression of the spruce if thinnings were delayed. Many American belts, with each row of a different species, have succeeded because of the wide interval between rows which have developed independently and therefore seldom attained the character of a mixed plantation. Any close intermingling of species depends for success upon the respective rates of growth on the site concerned; it is not always easy to forecast which will ultimately take the lead. For this reason there are better methods than making 'stem-by-stem' or 'line-by-line' mixtures. For example, patches, strips or small groups can be devoted to one variety to improve its chances against competition.

Assuming favourable site conditions, the major trees may be grouped as follows according to rate of development, starting with the fastest growers:

1. Hybrid poplars, cricket-bat willow, Douglas fir, Japanese larch, Sitka spruce;
2. Hybrid larch, sweet chestnut, western red cedar, birch;
3. European larch, western hemlock, alder, Norway maple, sycamore, ash, lime, elm, beech;
4. Corsican, Scots, Austrian and lodgepole pines, Norway spruce, silver fir, oak.

A similar grouping shows relative demands for light:

1. European and Japanese larches, birch;
2. Scots pine, poplars, willows, Corsican pine;
3. Oak, ash, sweet chestnut;
4. Elm, alder, Austrian pine;
5. Lime, Norway maple, sycamore, hazel, Douglas fir, Norway and Sitka spruces;
6. Hornbeam, western red cedar;
7. Silver fir, western hemlock;
8. Beech, box, holly, rhododendron, blackthorn, snowberry.

Groups 1 to 4 represent light-demanders, 5 moderate shade-bearers and 6 to 8 good shade-bearers.

Light-demanders in mixture, such as oak with ash, elm, sweet chestnut, alder, birch, Scots pine or larch, and Scots pine with birch or larch, are not suitable for shelterbelts unless a marginal row protects the structure from becoming open below the main crowns. Usually one species dominates, which is an argument for mixing by patches or groups rather than by individual plants or lines. Mixtures of light-demanders and shade-bearers provide a sounder basis, allowing a layered canopy for better wind protection. Oak, elm, ash or larch with beech or hornbeam; larch with Douglas fir; pines with beech, spruce or silver fir; and oak or ash with silver fir are examples. Sycamore in mixture is best planted in groups and the same applies to spruce-hardwood mixtures. Mixtures of shade-bearers by themselves are not common, except for the Continental silver fir with spruce or beech and Norway spruce with beech, and a group arrangement is again advisable.

Selection of Species and Composition. Having decided on the site and width of a new shelterbelt, selection of promising trees and mixtures may seem difficult. Expert advice, if necessary, can usually be obtained from local forestry officials. Without this, noting trees which do well in the district, especially on similar soils and aspects, can provide a safe guide. Five basic selections are advisable for mixed shelterbelts, more if greater variety is wanted: a species to grow fast for early shelter, even if comparatively short-lived; a more permanent, slow-growing species, perhaps the predominant timber tree in local hedgerows and woodlands, excluding quick-maturing, commercial plantations of course; a supplementary shade-bearing species if the last is light-demanding; hardy, wind-firm, minor trees for exposed edges; underwood species that will stand coppicing to preserve low cover or, alternatively, lower shrubs for margins or for a covert layer. Not all may be required for any one belt but this basic range of planting material will suffice to meet any planting pattern selected.

With two rows, one should be devoted to a quick-growing species, preferably interplanted with a shade-bearer to provide for both underwood and succession, beech for example. A further species to follow on should go in the second line, again interplanted with a coppice species or shrub. This is simpler than attempting to spread all varieties over both rows.

Three rows allow several combinations: main trees with broad crowns can be confined to the middle row to avoid overhang; wind-firm trees can form an exposed, outer edge; or all species may be distributed evenly over all the rows. With three species selected, the following arrangement has been successful:

1 2 3 2 1 2 3 2
2 3 2 3 2 3 2 3
3 2 1 2 3 2 1 2

where: 1 = fast-growing species
2 = shrub or shade-bearing underwood species;
3 = permanent species to take over from 1.

Alternatively, the pattern may be:

1 2 3 1 2 3 1 2 3
3 1 2 3 1 2 3 1 2
1 2 3 1 2 3 1 2 3

Where four species are used in three rows, the following scheme has been adopted in one German district:

4 3 2 1 4 3 2 1
1 2 3 4 1 2 3 4
4 3 2 1 4 3 2 1

where: 1 = fast-growing species;
2 = permanent species } one to be shade-tolerant;
3 = permanent species }
4 = shrub or underwood species.

A better distribution of the fast-growing trees may be obtained as follows, using the same notation:

1 2 3 4 1 2 3 4
4 1 2 3 4 1 2 3
1 2 3 4 1 2 3 4

These are 'stem-by-stem' mixtures and need to be closely watched to avoid unnecessary suppression of one or other species. With four and five rows and more it becomes progressively easier to achieve a suitable mixture by lines rather than stems. But adjacent rows should not have to compete strongly with one another; it is better to plant secondary or shade-tolerant trees alongside quick growers and light-demanders, which can

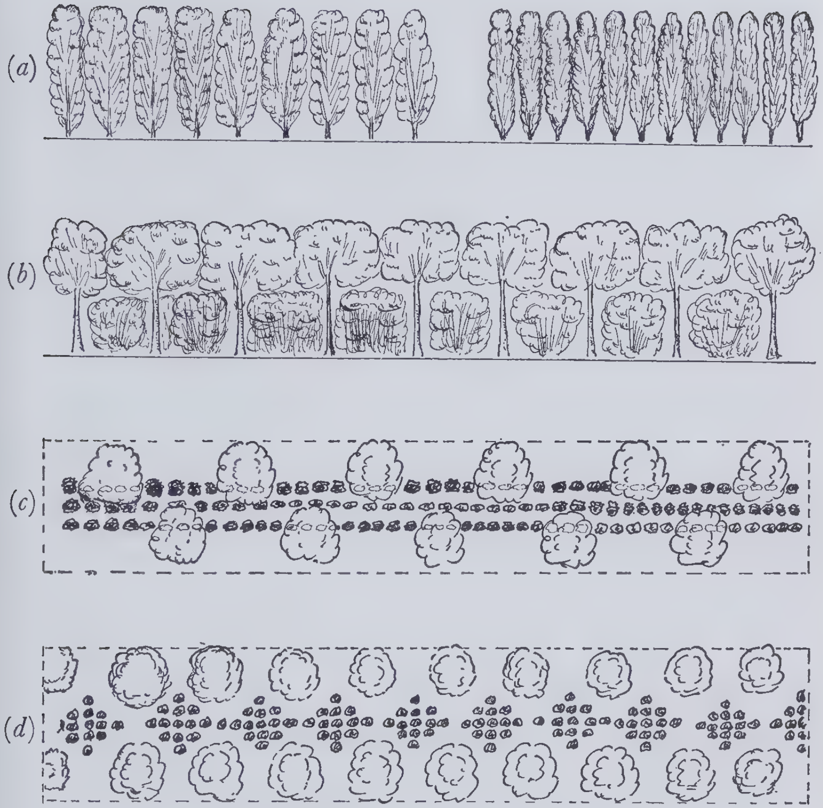


Fig. 30 Examples of poplar planting in shelterbelts: (a) single-row belts of fastigiate varieties require close spacing appropriate to their habit in order to be effective; (b) broad-crowned varieties require the support of an underwood or vigorous shrubs on the edges; (c) a double row of poplars with an underwood of three rows of shade-bearing shrubs and small trees; (d) a double row of poplars enclosing secondary species in a group arrangement.

be planted in alternate rows if required. Permanent, slow-developing species can be kept to centre or leeward rows, leaving the windward side for early height growth and shelter. There are innumerable examples of suitable shelterbelts having been formed along these general lines.

Two parallel lines of poplars, for instance, at 18 ft spacing within and between the lines can be supplemented by three lines of permanent, shade-bearing or underwood species in the centre at 3 ft apart, plants in the rows going 3–5 ft apart. On fertile ground in Germany, this system has been employed to grow poplars on a 30-year rotation. Half the poplars are removed every 15 years (thus, the first felling is made at 15 years old) and replaced by saplings to provide the cut for 30 years ahead.

On the sandy soils of Munster and Emsland, *Quercus robur* and *Q. borealis* often replace poplars as the principal trees, alder and birch providing early height and nursing the oak. A central row or two of oak, separated from a few rows of alder on the outsides by a line of mountain ash, is a typical example. On moister sites there may be a row each of balsam poplar, willow and alder with red oak and mountain ash dispersed in all three rows; or a row of *Populus robusta* interplanted with common alder, followed by a row of *Prunus serotina* and one of pedunculate oak, the oak being destined to assume the major role eventually.

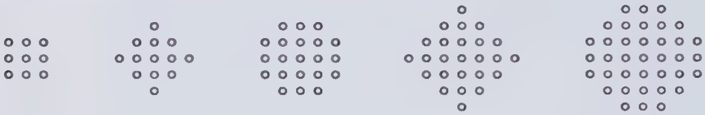
On the south-facing slope north of the Tay, the Scottish Horticultural Research Institute has provided shelter in record time with four-row belts, the rows and plants being at 6-ft intervals. Sitka spruce, Scots and Corsican pines have been mixed with beech, sycamore, maple and birch for additional winter protection but have been surpassed in growth by the birch and sycamore. Mechanical cultivation has been employed between the rows.

Belts of 5 and 7 rows at 4½ ft apart are common on Russian arable areas, although wider barrier belts in the Ukraine may have as many as 21 rows. The distance between rows is increased to 7½ ft if mechanical cultivation is practised to suppress weeds. A wide espacement of rows is found in most American shelterbelts, the conventional 10-row design having an overall width of 90 ft, although more interest is now being shown in narrower belts of 7 rows (60 ft) and 5 rows (40 ft). On the other hand, Canadians do not appear to favour wide spacings between rows in multiple-row belts and aim at an early closure of the canopy to check weed growth and moisture loss.

Russian planting authorities issue detailed prescriptions for the composition of field shelterbelts according to soil conditions and the type of structure required. For example, a windbreak 'penetrable below, complete above, with no underwood', generally of five rows, might contain three rows with alternate plants of pedunculate or red oak and Norway maple and two rows of small-leaved lime alternating with ash. A larch-ash type might have three rows of Siberian larch and Norway maple, always mixed in the lines, and two of ash and lime. Here, light-demanders or moderate shade-bearers predominate. In a second category, 'penetrable below, complete above, with low-growing underwood', ground shrubs are interspersed amongst tall-growing trees. In the birch-ash type, for example, three rows of birch, privet, field maple, privet (repeated) would be followed by two rows of ash, wayfaring tree, Norway maple, wayfaring tree (repeated) or alternative species of similar size and habit. In a third group, 'equally penetrable to wind from top to bottom', often referred to as 'latticed' structure, typical belts are of 5 or 7 rows. A pine-elm belt of 5 rows might have common pear, oak and privet on the outer rows, the next rows of Scots pine, Tartarian honeysuckle, small-leaved elm, Tartarian honeysuckle (repeated) and the centre row of white acacia, Tartarian maple, Norway maple, Tartarian maple (repeated). Poplars might replace pine, Norway maple the oak, crab apple the pear and privet the Tartarian maple and honeysuckle. A birch-elm mixture might be formed from outer rows of birch and golden currant, behind which there would be two rows (2nd and 6th) of small-leaved elm and golden currant, two rows (3rd and 5th) of birch and maple and a central line of elm and honeysuckle or acacia, making a total of 7 rows. In this group the selection provides for trees and shrubs of varied height and a higher proportion of species tolerant of a certain amount of shading.

These are examples from the wide variety of shelterbelts described in Russian literature. Naturally, many of the species listed would be unsuitable for British conditions but the principles for composing the different belt structures could easily be adopted. The 'latticed' type particularly would fit most arable farm requirements.

All the above are mixtures obtained by conventional, line-planting methods. An alternative that allows for more irregularity in the structure, desirable from the point of view of permanency, and creates fewer tending problems, at the same time giving a broken crown level, is to plant in groups. The underlying principle here is that each group of plants, closely planted within the group, ultimately provides one or two final crop trees. For shelterbelt purposes, the best groups are those of 9, 13, 21, 25 or 37 trees, planted around a central tree as shown below:



(a) 9 trees (b) 13 trees (c) 21 trees (d) 25 trees (e) 37 trees

These groups may touch but it is usual for an interval to be left in between to avoid undue competition and early attention. Suggested patterns are illustrated in Fig. 31 but these represent only a few of the possible combinations.

As with individual trees, groups should provide for the different kinds to be fairly well distributed, remembering that some will be removed before others. Alternatively, a simple, popular arrangement is to disperse groups of long-living species throughout a matrix of quick-growing or temporary varieties. On an East Lothian farm, for example, ash groups of 25–30 ft diameter containing about 40 plants per group are distributed in a 50-ft belt of European larch and Scots pine. In this case the conifers have nursed the hardwoods and a free-growing hawthorn hedge has maintained low cover on one side, otherwise a shrub layer would have been necessary as the conifers thinned out below. Taking a long-term view, it would have been better to include a secondary, shade-enduring species to

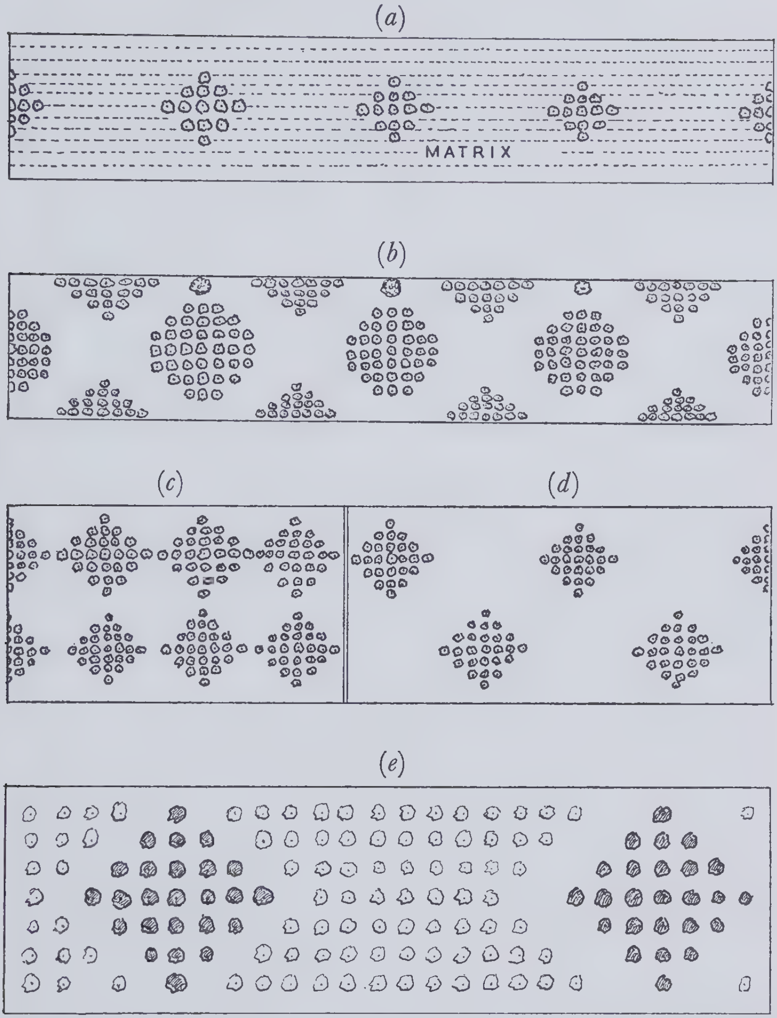


Fig. 31 *Group planting in shelterbelts:* (*a*) *widely spaced groups within a matrix of another species;* (*b*) *half-groups or wedges used to fill in margins;* (*c*) *groups can be contiguous or set apart;* (*d*) *the position of groups in subsequent rows should be staggered;* (*e*) *gaps can be left around groups if desired, lines in both groups and matrix corresponding.*

provide the cover in the middle layer that will be needed eventually.

Groups can be planted in random arrangement but adhering to lines has advantages for ease of planting and subsequent weeding and also allows both normal lines and groups to be incorporated in the same design, as illustrated in Fig. 31 Yet, mathematical precision as regards spacing is unnecessary and time-consuming; every effort should be made to make the planting scheme easy to follow and carry out.

UPLAND AND HILL FARM SHELTERBELTS

On enclosed upland farms, where belts normally follow field boundaries, the principles suggested for lowland shelterbelts can be applied, with a suitable change of species. On open hill and mountain grazings, on the other hand, getting something established in the right place is more important than particular structures. In both cases, the nature of the land formation and consequent complications imposed on the wind regime control to a large extent the shelter derived from a windbreak. Greater degrees of exposure, aggravated perhaps by poor soils, influence both the success and the performance of the planting.

Young trees benefit from protection so that on the hills where there is some latitude in choosing planting sites it is often wise to plant just to the lee of a minor eminence such as a spur or ridge rather than in the teeth of the wind. Rising ground behind a shelterbelt curtails the shelter, whereas a gentle fall on this side of the trees extends their effect, a further argument for selecting such a site. On steeper slopes, however, belts at the back of ridges may be overflowed by the wind and yield little protection. Wind damage commonly occurs at the foot and crest of a rise; beyond the crest there is a calm area, followed closely by a disturbed zone due to the wind breaking over the top that may also experience damage. Behind large ridges, where slopes fall away too sharply for the wind to follow, pockets of 'natural' shelter are useful for livestock but nearby there may be strong turbulence before the wind resumes its normal flow pattern.

Shelterbelts sited at the edge of this eddying area or to weaken winds falling over the crest can augment the 'natural' shelter.

Leeward slopes with gradients less than 1 in 4 or 5 lack 'natural' shelter of their own. The smooth, rounded profiles typical of much of the Southern Uplands are an example. Valleys canalize the wind, not with the intensity experienced in narrow, deeply-cut, Welsh valleys but appreciable nevertheless. Higher up, the wind largely clings to the contour and, as regards shelter, the flattened tops may be as favoured as leeward aspects. Here, successful belts have often been established on both windward and leeward edges of these broad ridges. In the valleys the best arrangement is one where belts run down the side slope at convenient intervals which are generally controlled by local circumstances like field boundaries or pasture management.

The intensity of planting must depend on usefulness to the individual farm. Amenity and timber possibilities may count also but it is shelter's potential contribution that usually predominates. In this connexion the choice between the traditional long shelterbelt and the more compact block, whether the latter be square, round, kidney- or diamond-shaped, or a Maltese-cross or Manx-leg, must be carefully made. These are not always alternatives but more frequently two distinct items of farm equipment: a straight choice between the two is mostly confined to the higher slopes and exposed tops of sheep walks, where winter storm protection, often against directions other than the prevailing wind, dominates the scene. Broken country like much of the Western Highlands offers a fair amount of 'natural' shelter and seldom accommodates long belts. Sudden contour changes would soon shorten their protective range. Here, small blocks may be more useful for safeguarding stock in severe weather and are more readily established than long strips where exposure and soil conditions are limiting factors. Because of their smaller cross-wind dimensions, blocks offer a limited sheltered zone but have the advantage of more than two sides to cater for different wind directions. On exposed high-lying grazings or in the middle of large upland fields or, again, taking in the corners of four fields at their central junction, such blocks can provide a refuge against cold winds and snow or shade in summer which may be equally important. For fields that are tilled on rotation, however, they should be restricted to patches unsuited to cropping, some of which are in any case used as dumps for ploughed-up stones.

Blocks are a different proposition of course from a long shelterbelt on the windward side of a pasture that allows stock to move and graze in a wide area of shelter even in the rawest weather. Small sheltered areas in which stock concentrate become over-used, fouled and poached, the consequences increasing where the grazing area itself is restricted. On the open hill where stock range at will and find alternative shelter in the ground formation the disadvantages of small blocks are fewer but on heavy and sticky land the blocks are least advisable.

Long belts, on the other hand, should avoid interfering with the natural "rake" of hill sheep or trapping on the exposed side animals driven before a blizzard. Fenced paths through long belts increase costs but may be justified. These will remain free of snow drifts only so long as the wind blows freely through them, which naturally reduces the leeward shelter but may be necessary. If laid out obliquely to the line of belt these paths keep out the wind but may not always be free of snow.

Not all shelterbelts need be long narrow ribbons: it may be convenient to fence off and plant any steep gullies likely to prove dangerous during snow storms, extending the planting up the

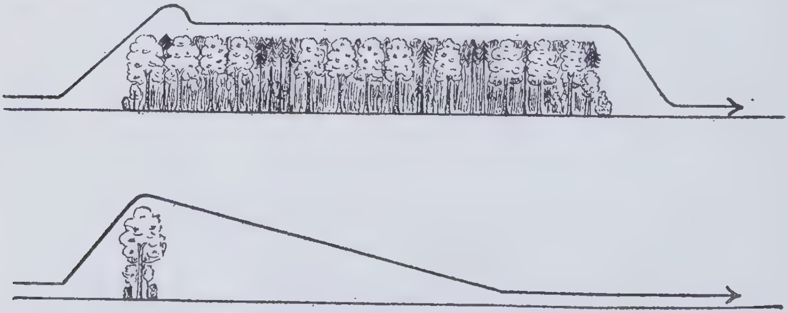


Fig. 32 The flow of wind over a narrow shelterbelt and a wide forest block.

banks to give suitable side shelter. If left unplanted, alternative accessible shelter can be provided some distance to windward of acknowledged danger spots. Gullies such as the Border 'cleughs' are not necessarily potential hazards; some afford valuable shelter which can frequently be enhanced by planting at the head to keep out cold air from the north and east or establishing a clump in the gully for overhead shelter on clear, cold nights.

Long shelterbelts materially improve the climate at the level which matters to stock and crops. In conjunction with pasture improvement and intensive management, a series of such belts can transform bleak hill and upland farms. But to secure such benefits over large areas of open grazing calls for an intensive and expensive network of shelterbelts which would be more appropriate where land values and production prospects are high. However, many exposed stock farms could benefit from more modest but well-planned shelter. For example, the contribution which one or two sheltered paddocks of 10, 20 or 30 acres on the lower hill ground might make to the productivity of a hill farm as a whole warrants serious consideration, as men-

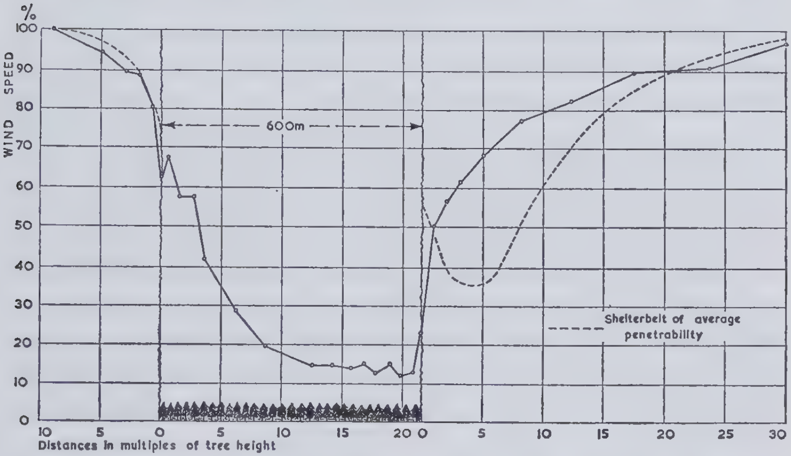


Fig. 33 Wind abatement behind a forest block compared with that leeward of an efficient shelterbelt (after Nägeli).

tioned earlier. These could alter significantly the economic prospects of the farm for an outlay which, if not cheap, would appear modest in relation to the total acreage. A square ten-acre paddock surrounded by a shelterbelt a chain wide would involve 4.4 acres of planting, the main obstacle being the 88 chains of fencing if no existing fences could be utilized to ease the burden. A second paddock alongside would require another 63 chains. Twenty- and thirty-acre enclosures of similar shape, the square being cheaper than the rectangle, would involve, respectively, 6 and nearly 7 acres of planting and 120 and about 145 chains of fencing. A solitary, mile-long shelterbelt on the open hill would cost more (162 chains of fence if 1 chain wide and more if wider) for possibly fewer benefits.

Lower rental values than in the lowlands mean more land is readily available for planting on upland farms. Consequently, wider belts can be entertained. The increased density and reduced permeability implied will mean some sacrifice as regards the range of wind protection to leeward but perhaps balanced by a greater wind reduction over this shorter distance. Apart from the annoying down-draughts provoked by the near-solid barrier, the total shelter produced is not necessarily very different from that behind the filtering type of structure; the difference lies in the leeward distribution of the shelter as illustrated in the following table.

TABLE 2

WIND REDUCTION TO LEEWARD OF 30-FT HIGH SHELTERBELTS OF DIFFERENT DENSITY

	PERCENTAGE WIND SPEED REDUCTION			
DENSITY OF BELT	*Averaged over first* 50 *yards*	*Averaged over first* 100 *yards*	*Averaged over first* 150 *yards*	*Averaged over first* 300 *yards*
Very open	18	24	25	18
Open	54	46	37	20
Medium	60	56	48	28
Dense	66	55	44	25
Very dense	66	48	37	20

For extensive sheltering the moderately dense belt gives the best average (28 per cent). Some at the top of this class may show an average wind speed reduction over 30 'shelterbelt-heights' down-wind of more than 30 per cent. On the other hand, if one is interested only in a narrow zone nearer the trees denser belts have the advantage (a 66 per cent reduction over the first 5 'shelterbelt-heights'). Some belts here have registered a drop in the wind of as much as 77 per cent but there is a good deal of variation according to the general weather position.

In exposed situations wider and therefore denser belts are easier to maintain and an irregular profile produced by an uneven crown canopy can help to counteract much of the eddying due to the wind stream being forced over the trees. As the width increases the wind has a tendency to strike the ground relatively soon after passing the trees but in Switzerland a spruce plantation, 30 chains wide and 90 ft high, still yielded a 45 per cent wind abatement over the first 150 yards (i.e. 5 'heights') to leeward and a 33 per cent reduction over 300 yards. Corresponding figures for narrower but very dense belts would be around 66 and 48 per cent, as in Table 2.

Widths variously recommended for upland and hill shelterbelts are neither here nor there. What matters most is a successful plantation. On soils that support trees with little difficulty narrow strips suffice, whereas poorer sites and exacting growth conditions suggest greater widths. Other factors must be considered: the space that can be released for planting, timber prospects, etc. Under severe exposure, establishment and subsequent treatment of a belt are greatly simplified where the width is not less than two chains; elsewhere, a chain will generally be sufficient. Naturally, timber producing belts should be wider since conditions approaching those in the forest are then developed more readily. A drawback experienced with wide belts in some districts is the heavy damage sustained due to snow breakage; Scots pine belts are especially vulnerable.

On hill and upland it is even more important to take advantage of any existing hedgerows or tree groups that may aid establishment of new belts and increase the total shelter obtained. Old turf dykes, mounds from former hedges and stone walls can cut a few years off the waiting period until belts become effective. Planning for wind-firmness and eventual regeneration is also more important than on lowland ground. Rapid height growth may be desirable but not at the cost of stability in high winds. Similarly, many existing ill-planned strips offer no prospect of permanence and problems now confronting many owners of pure conifer shelterbelts, 30 years old and upwards, could have been avoided at planting. Those that are open and draughty below, sometimes dense in the crowns, sometimes decimated by gales, or blasted and frayed by wind action are not easily restored without risk of losing whatever shelter they provide during the process.

The typical belt on the German Westerwald, at about 1,000 ft, has for over a century been a spruce strip, 50 yards or so wide. For continuity an adjacent strip is planted some years before the first is felled. A similar policy could be useful elsewhere, except on arable land where stumps would be a nuisance. But for all coniferous shelterbelts in windy districts and especially those planted pure a minimum precaution should be a strong, hardy, wind-firm margin for the windward edge at least. Sycamore, beech, hawthorn, rowan, whitebeam, rhododendron, laurel, lodgepole and mountain pines, on appropriate sites, are valuable edging species, Relatively long-lived margins mean protection of the stand during gales and provide acceptable shelter when the plantation is thinned or even clear-felled. Margins that include a shrub or hedge layer for low shelter are invaluable when replanting, checking winds that would otherwise sweep through at accelerated speeds and render establishment of new trees difficult and costly.

Wide belts can also be strengthened with an inner core of slow-maturing, deep-rooted species. Sessile oak, beech, sycamore, horse chestnut and lime, for example, meet the case on the right soils. The leeward portion of such belts can frequently produce timber for sale or farm use. On a livestock-rearing farm at 1,250 ft in Midlothian a 3-chain wide belt occupying 20 acres consists of a windward margin of rowan and mountain pine, supported by several rows of lodgepole and Scots pine, a band of beech, 4 rows of oak, another band of beech, then 1½ chains of Scots pine/silver fir and Japanese larch/Sitka spruce mixtures for timber. The leeward margin and ends have a row of sycamore with beech.

Mixing by strips introduces variety and offers better insurance against failure. The Forestry Commission pamphlet *Shelterbelts for Western Hill Farms* adopts this method for its suggestions, e.g. a 2-chain wide composed of a shrub border, ¼-chain white spruce, ¾-chain Sitka spruce, ½-chain beech and ½-chain Sitka spruce or Japanese larch; or, more simply, ½-width Sitka spruce and ½-width beech or Japanese larch. Fast-growing trees in the leeward section are recommended for early shelter for stock. In most cases the slow development of white spruce could prove a disadvantage, creating the sloping windward face that is no longer favoured. In other respects this arrangement of species improves upon the pure stand and possible variations on these lines are many.

From the point of view of achieving an irregular profile to break up the wind stream still more and to ease long-term management, an even better scheme is to mix species by groups rather than continuous bands. Few planters want a patchwork composition but it is a simple matter to disperse through the planting a limited number of groups or patches, possibly of fast growers for tall shelter, long-lived species for stability and succession, or shade-bearers for low cover. Taking for the sake of illustration a hypothetical case of planning a simple shelterbelt 1 chain wide and 20 chains long on an upland site, where the soil is a well-drained sand and gravel over boulder till and the district relatively dry, Scots pine, larch, beech and sycamore would represent a reasonable choice of species. For this area of 2 acres, total plant requirements assuming a spacing of 5 ft × 5 ft would be 3,484 (1,742 trees per acre), say, 3,500. Of these, 3,000 could be pines, leaving 500 available for other species and allowing 20–25-tree groups, perhaps 10 of sycamore and 10 of larch. If these groups were arranged in a single line through this narrow belt, there would be one group per chain. Once the boundaries were demarcated, on a centre line and half a chain from the end of the belt the position of the centre of the first group would be marked, further centres being marked at one-chain intervals thereafter. The groups, alternately of sycamore and larch, would be planted first, then the pine matrix. A strip 66 ft wide allows 13 rows at 5 ft intervals with 3 ft between outside rows and fences. Trees at 5 ft spacing in the groups would conform to the pine rows; closer spacing within groups would necessitate an interruption in the lines but could leave more space around the groups, thus reducing future competition. Beech might be brought in later, perhaps to replace the larch which could be removed as young poles or, alternatively, to form an understorey for the pine after a third or fourth thinning.

Instead of a matrix species, group planting can be used throughout, groups being contiguous or set a short distance apart. Half-groups or small triangular groups will fill in the spaces along the margins. With more than one row of groups, their positions in adjoining rows should be staggered to keep out the wind (see Fig. 31 (*b*), (*d*). Spaced groups require little maintenance after the weeding stage, being slow to compete with one another, but if too varied a selection of species is used or if the groups are only thinly spread over the site there is inevitable delay until the belt begins to function. It is important to provide a sufficient density of reliable, readily established trees and a small proportion only of slow developers that may require nursing. With species like oak, unless the site is very favourable for its establishment it is often better to make use of a pioneer species like grey alder, which will give good shelter as well as prepare the ground, and introduce the oak at a later stage.

Narrow belts of a chain in width have to be content with groups of 37 trees or less; wider belts may contain even larger groups. With 25- or 37-tree groups at 3 ft spacing in the groups the centres must be at least 24 ft apart if groups are intended to meet from the start and more if not. With an overall group arrangement conventional planting lines are naturally abandoned and the centres only may be lined up.

Group plantings afford the fullest opportunity for mixing species, nursing difficult varieties and carrying out subsequent changes in the structure or composition of a shelterbelt. It is not usual to mix the species in individual groups; abrupt changes in soil or light across the site of a group are best accommodated by shifting the position.

PLANTING PRACTICE

Spacing. Wide intervals between trees reduce planting costs but the optimum spacing depends upon growth rates in early youth. Fast-growing species on good sites require fairly wide planting distances; slow growers on poor or exposed ground and most hardwoods benefit from closer planting. Shade-bearers are also more tolerant of crowded conditions than light-demanders. Poplars need most room and, except where they are planted initially as close as 6 ft in single-row windbreaks, should be no nearer than 15 ft for columnar varieties and 18–30 ft for broader crowned types.

Common practice at present is to plant the slower growing conifers, such as Scots and lodgepole pines and Norway spruce, at 4½–5 ft, Corsican pine and *Tsuga* at 5 ft and faster growers at 5–6 ft. Occasionally, Japanese and hybrid larches and Douglas fir on favourable ground are up to 7 or 8 ft apart. An interval of 3–4 ft is normal for most hardwoods although 4–5 ft is used with sycamore and 5–6 ft is advisable for alder on good sites.

Tree Requirements. Plants required per acre depend upon the planting scheme as well as upon the spacing between and within rows. 'Square' planting, where the distance between rows and plants is the same, is simplest. 'Rectangular' planting, as its name implies, is only slightly different. In 'triangular' planting, correctly interpreted, each tree is equidistant from its neighbours in the same and adjoining rows, the trees in one row being opposite the spaces between plants in the next. Thus, for 5 ft triangular spacing the rows are 4 ft 4 in. apart and 15½ per cent more trees are required per acre than for square or rectangular planting. In practice, true triangular planting is fiddling and unnecessary; it is more acceptable to adopt a round figure for the spacing within and between rows. If so desired, trees can still be planted in an echelon, the trees in one row opposite the gaps in the next so that, for a 5 ft interval between and within rows, each tree is actually 5 ft 7 in. from its neighbour in the adjacent row; planting is therefore on the triangle but not the equilateral triangle and plant requirements are as for square planting at that particular spacing.

The so-called 'quincunx' planting design, a term that makes planting sound more difficult than it is, is simply square or rectangular planting with a fifth tree placed in the centre of each four, thereby doubling the number of rows and, in effect, producing nothing more than the modified form of triangular planting described above.

Tree requirements are calculated by dividing the number of square feet in one acre (43,560) by the product of the spacing between and within rows. Thus, for rows 5 ft apart and trees 4 ft apart within the row, the requirement per acre is 43,560/20 or 2,178. A table of plant requirements is given, for easy reference, in the Appendix (p. 281).

Preparation of the Planting Site

Drainage. Drainage of wet sites is essential for most species, although common alder and sallow tolerate extremely marshy conditions like East Anglian carrs. On agricultural land the water can usually be diverted into existing drainage channels if the fall is adequate. Failing this, deep ditches, with the spoil thrown up into banks on which trees root above the water table and gradually lower it, have resulted in good plantations of oak in Norfolk and beech in Scotland. Open drains are the rule; pipes become choked with roots, a point to bear in mind if field drains near the surface pass through a planting site.

On upland slopes contour drains above the planting area divert the run-off from higher ground. Main channels, supplied by short feeder drains in herring-bone design, require a gradual

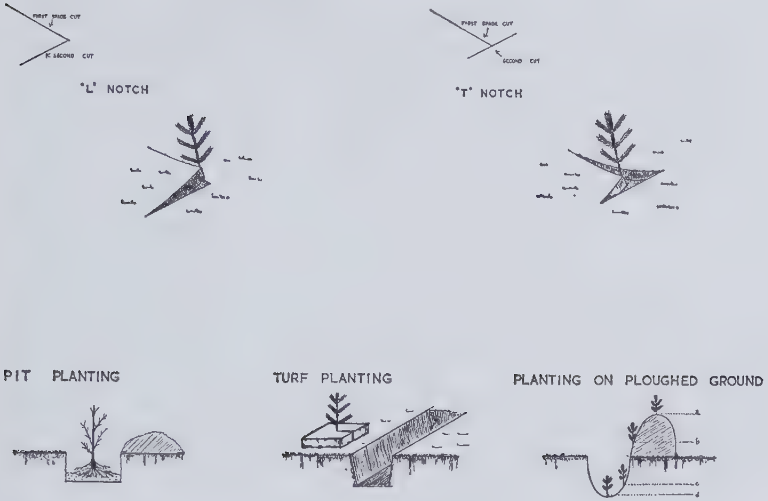


Fig. 34 *Method of notch planting: (a) 'L' notch; (b) 'T' notch. Pit and turf planting and method of planting on land ploughed by drainage ploughs. Note possible positions for planting: (a) on top of the upturned ridge; (b) on the side of the ridge; (c) on the furrow side; (d) on the furrow bottom.*

fall. Up-and-down drains on moderate to steep slopes with loose soils rarely function efficiently and may scour alarmingly after heavy rain.

The layout and size of drains depend on local soils and conditions. A common size is 12–18 in. deep, 24 in. wide at the top and 9 in. at the bottom, main ditches being 3 ft deep and 15 in. across the bottom. On wet peat areas, intervals of 15–30 ft between drains are common; there is much regional variation in practice which is tied to the need for ploughing. Drainage ploughs in recent years have improved extensive areas of hill grazings and extended afforestation to sites formerly unplantable. For the larger belts on hill land this kind of equipment may be available on contract but for smaller areas and those of poor access manual methods are unavoidable.

Adequate drainage and proper maintenance are insurances against plantation failures or serious checking. Even small wet spots in a shelterbelt warrant extra attention.

Ploughing. On upland peats drainage may be combined with ploughing to produce the turf for planting which experience has shown to be essential on all but the best flush peats. On difficult peats requiring much drainage a double-mouldboard plough cuts shallow furrows 10 ft apart and leaves turf ridges lying 5 ft apart. Single-mouldboard types turn out deeper drains as required. Deep furrows cut at 20-ft intervals will provide enough sliced turfs to spread between the drains.

Cultivation on heathlands before planting promotes aeration of the surface peat and breaks up the hard pan which is usually near the surface on iron or peaty podsols. Shallow furrows for every line of trees are generally sufficient, although more intensive cultivation is usually repaid by better growth. Deep subsoiling tines shatter the pan, which is otherwise impenetrable to roots.

On most farmland ploughing furrows for the tree lines gets plants away to a better start and reduces failures. Subsequent weeding is easier and less costly than on unploughed ground. Complete ploughing, in all cases, reduces competition from grass and weeds to a minimum and, on all but loose soils, allows better rooting, avoiding the dangers of roots keeping to the ridge or furrow. Fallowing the ground the season before planting is standard practice in North America to increase the moisture reserve in the soil and this could help some particularly dry sites in Britain.

Fencing. Fencing costs account for the comparatively high costs per acre in shelterbelt planting. Extra fencing for Continental shelterbelts is often avoided; instead, electric fences follow livestock from field to field. Where rabbits, hares and roe deer present no serious problem, lowland farmers might dispense with extra fences. But in most cases reasonably permanent fences are necessary, a fact which controls to some extent the site and shape of new belts. Where an existing fence can be utilized for one side of a belt, the outlay can be almost halved.

Since the spread of *myxomatosis* the rabbit population has dwindled but is again rising in some regions. Hares have probably increased and cause serious damage in many new belts and especially when snow drifts against plantation fences and gives them entry. Broadleaved trees can recover, given the chance, but persistent nipping back causes heavy losses and delay. Conifers succumb more readily if damaged and loss of the leading shoot generally spoils the tree.

Effective rabbit-proof fences are constructed from 17 or 18 gauge wire netting of 1¼ in. mesh and 42 in. deep, the bottom 6 in. being buried in the ground or, more common nowadays, bent outwards on the surface and held down by sods until grass grows through and anchors it. Dual-mesh wire can be cheaper, the top 18 in. having 1½ in. mesh. A top plain wire of No. 8 gauge with a second wire near the bottom, fixed to 5-ft stakes of 2–3 in. diameter at 10–12 ft intervals, provides adequate support. Straining posts 6 ft long and 6 in. top diameter are required every 100 yards or so and at all definite changes in direction.

Usually protection against rabbits is combined with a stock fence. To deter sheep slightly stouter, longer strainers are advisable, with 4–6 plain wires if no sheep or rabbit netting is used and 2–3 wires if 4-in. mesh or rabbit netting is available. Against cattle, the top wire and perhaps one or two others can be replaced by barbed wire.

Deer may incur protection fences. Although the red deer is confined to Highland areas, roe deer are more widespread and clearly responsible for much damage that was formerly attributed to rabbits. Various repellants are now on the market and there are other preventive measures such as the German idea of winding a length of wire loosely round poplars and willows to prevent rubbing, kinking the wire so that it rusts through after a few years and falls off. If there is no alternative, a satisfactory deer fence requires posts 8–9 ft long by 3 in. top diameter at intervals of 18–24 ft, with droppers 1 in. by 1½ in. by 3½ ft every 3 ft or so. At least 8 wires are necessary, both plain and barbed, including those attached to the normal stock fence below; netting is still essential at the bottom to keep out roe deer. Strong stays are needed to ease the considerable strain on the posts, particularly when snow is drifting.

Fenced shelterbelts need a simple lift-gate for access and to let out stock that may have negotiated the fences. The cost amounts to little more than an extra strainer.

Ordering Plants. Sturdy transplants with well developed root systems are recommended. As a rule young plants withstand the shock of planting better than larger ones, although quite tall transplants were once used in Britain and still are on the Continent. On good sites the latter may develop successfully but their use can only be advised with any degree of assurance if planting can be carried out with the minimum disturbance of the roots and if the exposure is not likely to cause swaying and loosening. Where a plot is available, perhaps in a garden, seedlings or first-year transplants can be bought in a year or two before the plantation is made and transplanted on the home ground. This cuts costs, provides bigger trees for planting and the plants can be transferred to the site with little disturbance whenever the weather is favourable.

Small plants tend to be overwhelmed by weed growth and prolong weeding operations but are essential on windy and poor sites. Trees over 2 ft in height would also require staking. Most hardwoods are best purchased as 2-year seedlings that have been undercut in the nursery beds to provide good roots, or 2 yr 1 yr (2 + 1) transplants that have had two seasons in seedbeds and one transplanted. One-year seedlings may be suitable if well-grown. Exceptions to this rule are poplars and willows, which are supplied as unrooted or 2–3 year, rooted cuttings or sets; cricket-bat willow sets may be 10 ft tall. Most conifers should be 2 + 2, 2 + 1 or 1 + 1 transplants, 12–15 in. tall, although smaller plants of 6–10 in. may be more suitable for planting on very exposed sites where there is little weed competition due to ploughing.

Trees should be ordered well in advance, stating the purpose for which they are intended, from a reputable forest nursery accustomed to supplying trees for forest planting. Firms which specialize in the sale of individual specimen trees may not quote for large quantities. Competitive quotations, and samples of plants offered, are available from "forest tree" nurserymen whose names and addresses can be obtained from the Royal Forestry Society of England and Wales or the Royal Scottish Forestry Society. Less risk of losses due to environmental change is involved if plants are obtained from a nursery in a more rigorous area rather than from a mild district.

As soon as plants arrive they should be heeled-in or 'sheughed' in a prepared trench, covering the roots with moist earth. Bundles, placed side by side, should be opened out if they are to be in the trench more than a few days. A straw covering keeps off frost. During handling at all times tree roots must never be exposed to drying winds, otherwise casualties will occur. These are small points but easily overlooked.

Time of Planting. Ideally, the time for planting is during the winter dormancy of the trees, from late October to early April. Autumn planting has its advocates, more so for the planting of hardwoods and larch which flushes early; the argument being that trees are better established when spring comes and suffer less of a check. On the other hand, these trees are more liable to suffer from winter wind and frost. Spring planting is more common, continuing into May at later and higher elevations and perhaps even longer with plants which have been in cold storage all winter. In general, the earlier the better, provided the weather is open and the ground free of frost. Late planting provokes failures, normally as a result of cold drying winds that appear in spring, but conifers such as Lawson's cypress are better planted when winter cold is off the soil if the water supply to the roots can be maintained.

Planting Methods. Pit planting, whereby each tree is planted in a hole large enough to accommodate the spread-out roots, is normal gardening practice. It is worthwhile with large or valuable plants and on stiffish soils that lack aeration or old woodland sites. When large planting areas are involved notch planting is customary, except when faced with light crumbly soils which may have been ploughed. Notches are cut in the form of an 'L' or 'T', more rarely an 'E' or 'H', by means of an ordinary garden spade. In the case of 'L' and 'T' notches (Fig. 34), the second spade cut is at right angles to the first; the spade is then levered to raise a corner of the notch for inserting the plant. The young tree is then drawn up slightly to straighten the roots and the ground firmed round about. Twisting or bunching the roots should be avoided. On unploughed ground, a small area screefed around each plant will reduce weed competition.

Notch planting, or a modification of the notch and pit methods, can be applied in plough furrows or on ridges. On peaty ground plants are preferably not placed on the tops of turf ridges, where, although above the water that lies in the furrows for long periods, they will suffer in a dry season when peat shrinks. On the wettest sites, with rainfalls over 35 in. annually, plants should be placed on the ridge side away from the wind. On drier but heavy soils, the furrow side is preferable and furrow planting should be adopted on the driest areas.

V-shaped notches can be cut out of the side of plough ridges and the plant inserted before replacing the wedge. On unploughed, wet, hill land that is slow to drain, squares of turf can be upturned and the trees planted through the turf. A single side notch from the centre of the turf towards one side (Fig. 34) will enable the tree to be slipped into the slit and then firmed. Similarly, turf slices 4–6 in. thick. cut from drainage plough ridges and spread out at the required planting distance, can be notched. The tree roots then lie between two surfaces of vegetation which soon decompose; but air pockets in this sandwich can cause failures and turfs, like plough ridges, should have time to settle before planting. One disadvantage of the side notch is that it may dry out and gape in dry weather; such gaps need to be closed if observed but can be avoided on single turfs by the slower method of cutting a 'T' notch which does not split the edges of the sod. Exposed roots must be avoided and seedlings with shorter roots than transplants need to be planted more deeply, especially where droughts are likely or the peat is friable.

Planting can also be effected with a mattock or one of many planting spades which have been introduced. Although there may be a local preference for a particular tool, the ordinary garden spade meets most requirements. Mechanized planting, uncommon in British forestry, has superseded hand methods on the extensive plains country of North America, even on undulating ground. Neighbouring farmers, grouped into planting associations similar to those in parts of Germany, often share the hire or purchase of a planting machine in Canada and designs have been made available for local construction of machines largely from parts already used in other pieces of machinery, thus reducing costs.

Manuring. Fertilizers are seldom needed to encourage growth, except on the poorest peats and heaths, the former typified by cross-leaved heath (*Erica tetralix*) deer grass (*Trichophorum caespitosum = Scirpus caespitosus*), or cotton grass (*Eriophorum* spp.), the latter by stunted ling (*Calluna vulgaris*), and frequent deer grass. Small quantities (1½–2 oz.) of finely ground mineral phosphate, applied around each tree at planting or soon after, are mostly beneficial, although less essential to pines which should not be treated on *Molinia* or better peats but elsewhere may respond to applications.

Mulching. Different opinions are expressed concerning the advisability of mulching farm shelterbelts with straw or potato haulms. American objections to the practice have been that mulching prevents light rain from reaching the soil, harbours rodents, presents a fire hazard, induces shallow rooting and is therefore harmful to growth and survival. Some criticism has been raised in Denmark, especially as regards rodent damage, whilst in Schleswig-Holstein, Westphalia and Saskatchewan experience has shown mulching to be beneficial, safeguarding light soils from blowing pending establishment of the trees, reducing evaporation from the soil, suppressing weeds and increasing the water-retentive capacity of the upper soil horizons due to an improved organic content.

Replacing Failures. In narrow belts it is important to replace any failed trees during the first or second season after planting. In wider belts, unless casualties amount to 10–15 per cent, this is less essential. The criterion must be whether the gaps are sufficient to jeopardize development of the appropriate structure or impair the sheltering effect. The same species as the original can be used for replacements or variety can be introduced at this stage if required, provided the choice does not concern slow-growing species likely to be outstripped and suppressed by the older trees. Failures should be assessed before leaf-fall, which allows reasonable time for ordering plants.

Weeding. A strong growth of weeds or a tight grass sward suffocates young trees or deprives them of moisture that is much needed for early root development. Tall grass and bracken are liable to smother them when dying leaves and fronds collapse under rain and snow, in spite of having given useful shelter in the summer months. On unploughed heather ground removal or suppression of the heather around spruces is essential.

All ground vegetation flourishes when relieved of grazing. Weeding of young shelterbelts may continue for three or four years, until the trees are out of danger. Weeding is expensive, tedious and perhaps hazardous for the young plants if they are difficult to locate. Ploughing prior to planting can be a boon. Failing this, lines and groups need careful marking, single conifers making useful markers for hardwood rows and groups that are not readily seen.

Small sickles are most useful for weeding; but there are those who swear by tramping down the vegetation around the trees as an alternative to cutting, unless coarse, tussocky grasses are present. Paper bags from feeding stuffs and fertilizers, weighted down with sods or clods, and with the tree planted through the centre, have saved weeding costs and acted as mulches in some recent farm shelterbelts. Black polythene sheeting, popular in market gardens, has also aided the establishment of difficult specimen trees in an odd trial but cannot be recommended where there is a danger of its being blown into fields used by livestock.

Late weeding should be avoided since it increases the risk of injury by early autumnal frosts. Once the plantation is established, little attention is normally required for some years, beyond ensuring that drains are kept free, fences maintained and no avoidable disaster such as fire or the spread of crop weed-killers reaches the young shelterbelt.

10 Maintenance and Restoration of Old Shelterbelts

MAINTENANCE

The care of a shelterbelt is a continuous responsibility but rarely burdensome; there are occasional peak periods and times when little attention is needed. As the trees grow and their branches meet and intertwine to form the thicket stage, the struggle for survival and supremacy begins. Weeding is no longer necessary but, between seven and ten years after planting, depending upon the rate of growth and the density of the planting, it is wise to remove any woody climbers, like honeysuckle and ivy, which may be throttling the young trees or threatening to do so, together with unwanted wilding plants that may have appeared. Bramble or gorse may have become a nuisance; birch and sallow seedlings or coppice shoots from old hardwood stumps may be in danger of choking the planted species. Material worthy of retention should be kept as underwood but not at the expense of planted trees. In addition, wolf trees which, through rank and coarse growth, are classed as undesirable have to be removed wherever they endanger adjacent, good trees.

This cleaning is sometimes combined with brashing or 'brushing up' the young trees, involving the removal with billhook or pruning saw of side branches up to 5 or 6 ft above ground. In forest plantations this is done generally some time after the first ten years, as a preparation for thinning, in order to allow access and improve the knot-free quality of the timber. In a shelterbelt with a predominance of conifers the interior can be brashed to make the structure more penetrable to wind, but it may be dangerous to extend the treatment to the outside rows unless there is shrubby growth on the margins.

Thinning. During the dense thicket stage, trees begin to compete strongly with their neighbours for light and space. Unless thinned out, whippy weakly stems with small crowns develop and the slow growers in particular are suppressed unnecessarily, impairing the well-being of the plantation. A first thinning may take place anywhere between 12 and 20 years after planting, by which time the main species should have attained a height of 20 or 30 ft. The proportion of crown to bare stem can be an indication of the need for thinning; with most conifers, for example, the ratio should be 1:2 to 1:3, or 2:3 with larch.

The main object in thinning is to give the trees of the overwood more room for vigorous, unrestricted growth, so that the closer the initial spacing the earlier will attention be required. Thinning may be a little earlier or heavier in the outer rows of a shelterbelt, in order to encourage branching and wind-firmness, and is advisable with conifers.

'Little and often' might be a suitable motto to observe in shelterbelt thinning, excluding those belts that are two chains or more wide and therefore more amenable to thinning techniques employed in commercial forest practice. With most hardwoods, Scots pine and Norway spruce, a thinning every four or five years should be adequate; with faster growing species like European and Japanese larches and ash an interval of three or four years is better, perhaps no more than three years in good stands of Japanese and hybrid larches, Douglas fir and Sitka spruce. After each interval, the main species should have put on another 5 to 8 ft in height.

Intimate mixtures require a close watch to maintain the balance amongst the species. It is advisable to assess the position in late summer shortly before deciduous trees lose their leaves;

crowding will then appear at its maximum and a decision can be taken as to thinning, which is best done during the dormant season.

For thinning purposes, trees are grouped into four major categories: *dominants* are the tallest trees; *co-dominants* are less tall but still in the uppermost crown canopy; *sub-dominants* are not exactly in the upper canopy yet not directly overshaded; whilst the *suppressed* trees have no direct access to light, their crowns being below others in the stand. In addition, there are the large, mis-shapen *wolf trees*, the long, spindly *whips* which damage other trees as they sway in the wind, and the *dead and dying*.

Thinnings fall into two main types and several grades of intensity. *Low thinnings* remove those trees which have been left behind in the struggle, the emphasis being on retaining a large number of well-grown trees from which the final stand can be selected. *Crown thinnings*, on the other hand, are concerned mainly with reducing competition within the dominant classes, so as to favour the development of selected stems from an early stage; many dominated stems are left except where dying or diseased. Low thinnings, which produce uniformity in the stand, have been more usual in British forestry but crown thinning is now gaining ground. From the point of view of managing shelterbelts, crown thinnings have the advantage of keeping a greater number of smaller trees and of breaking the crown region into different storeys. In this way there is a better density distribution throughout the height of the belt.

The biggest problem is knowing now heavily to thin. The crowns of the main trees must be freed from crowding and the character of any mixtures needs to be preserved, which calls for sufficient light for the development of secondary species according to their tolerance of shade. This tolerance tends to narrow as one proceeds northwards. In light, low thinnings, the overhead canopy is not broken to any extent. A moderate grade opens up about one-fifth to the sky and a heavier grade probably one-third. Light, crown thinnings remove only a limited number of dominant trees but heavier grades aim at freeing as many as a hundred of the best stems to the acre from all neighbouring competition.

For all practical purposes there is a rough relationship between the height of a tree and its distance from neighbours in the same crown storey. With shade-tolerant species the spacing after thinning should be approximately one-sixth of the average height. Less tolerant species require slightly more room, say a spacing between trees of one-fifth of the height. For light-demanders the ratio should be one-quarter, i.e. 10 ft spaces between larches with a mean height of 40 ft. There may be other trees between these, either sub-dominant light-demanders or shade-bearing varieties which are quite happy to be overshaded.

With narrow shelterbelts the permeability of the structure must be preserved at the optimum level when marking trees for thinning. At times it may be merely a case of thinning out the underwood, if present, in order to let through a little more wind. Broadleaved species in the underwood can mostly be coppiced, either taking a whole row at a time or just odd trees here and there. Experience will show when this is necessary.

Judging the 'moderate penetrability' of a structure so often advocated is problematical. However, there are two simple 'rule of thumb' methods that may prove useful. Firstly, with a belt structure which is moderately open to the wind, one should be able to see a dappled light effect when looking straight through and these patches and pinpoints of light should be fairly evenly distributed. Standing close to one margin, it should be possible to see the colour of a field on the other side but not to make out, easily at least, the nature of the crop. Likewise, it should be easy to discern movement on the far side of the belt but not to pick out in outline the animal or machine that moves.

A second method, requiring little effort, is to walk with the wind towards the shelterbelt when a fair breeze is blowing. The wind decreases as the windward margin is approached but, if it should suddenly accelerate again near the trees, which often happens with tall belts that have opened out too much near the ground, then the underwood is not sufficiently dense. A windward edging of shrubs would also have overcome this. The same applies if there is much wind at all on the leeward edge. Further down-wind, it should be possible to feel the wind gradually weaken, reaching its minimum somewhere between two and five 'shelterbelt-heights' from the belt; after this point it rises again. With practice it should not be too difficult to locate this minimum point. If there is no noticeable slackening off of the wind as one walks out from the shelterbelt but, instead, a perceptible if gradual rise right from the leeward edge until the wind is really strong by about eight or ten 'heights' from the trees, then the structure is evidently dense by arable farm standards and should be thinned.

Underplanting. All but the narrowest of young plantations are dense until after the first or second thinnings at least. In order to prevent the mid and bottom sections of uniform stands from becoming too penetrable later on, underplanting may be the simplest method. The stand to be underplanted should be of a light-foliaged species such as ash, oak and larch, or else thinned more heavily, so as to reduce the shading effect. The underplanted species should be shade-bearing. Narrow belts have the advantage of additional light from the sides so that it may not be necessary to open out the overwood as much as in ordinary forest blocks. Nevertheless, a degree of thinning is usually essential, bearing in mind the need to maintain a good stand without losing the moderately dense structure. If dappled shade is produced on the ground beneath the trees there should be sufficient light for the establishment of shade-tolerant trees.

Strong shade-bearers like beech, hornbeam, western hemlock, western red cedar and silver firs can withstand fairly dense shade for several years after planting and still come away quickly given extra light later on. Species such as sycamore, oak, lime, Norway maple, Douglas fir and Norway spruce tolerate quite thick overhead shade for the first two or three years but thereafter need more light and the overwood must be thinned appropriately. Smaller species, holly, hazel, box and blackthorn, for example, can be introduced by means of underplanting, together with game covert shrubs such as laurels, privet, dogwood, raspberry and snowberry. A profusion of shrubs in an underwood may be interesting but should not, in a shelterbelt, become too dense.

A few planters may find it handy or expedient not to stock a belt fully right from the start but to leave space for subsequent introductions. More light permits a wider choice of species than is possible with underplanting. The main value of such a scheme is found where a particularly desirable species cannot be established directly on bare ground and needs the protection of a growing stand for success.

Pruning. Pruning shelterbelt trees, though a possible pastime, is seldom an economic proposition, except in the case of poplars or cricket-bat willows or other quality trees. Most trees prune themselves fairly well if grown in an association of others. Regular pruning of poplars is essential to obtain a good clear bole free of branches and knots in the timber and a modest amount of pruning may be worthwhile in other cases in order to relieve excessive competition temporarily. Pruning of all species is best accomplished with a saw or knife-edged tool during the winter and not when the sap is rising. Birch, for example, bleeds excessively if pruned too late.

Regeneration. The idea of woodlands regenerating themselves naturally when the time comes is like a shining star to budding foresters, but one that may tarnish in the light of later experience. However romantic Nature's process of perpetuating forests by self-sown seedlings may appear, it is a common error to suppose that this is always more economical than, or preferable to, artificial methods of planting. Natural regeneration in managed forests involves the deliberate opening-out of mature woods, either in groups or strips or by leaving seed trees at intervals over a whole block. The mother trees are gradually reduced in numbers over a pre-arranged period of years. Felling operations ought to coincide with good seed years. Furthermore, the soil must be receptive for quick germination and seedling establishment. If seeding is not successful within the first few seasons, soil conditions may deteriorate from exposure to light and weather and grasses and weeds take over. Rather than wait for natural restocking, it is often better to replant. In narrow shelterbelts it is rarely possible to achieve natural regeneration.

The best system of shelterbelt management is to clear groups, probably 10 yards and upwards in diameter, when the plantation approaches maturity, making sure that enough light reaches the ground. If seeding takes place naturally, all well and good; if not, then it is wise to replant without delay. With such groups the whole area can be worked over gradually, until the new patches join up and a new generation is established. The operation is greatly simplified if there is a good windward margin, giving more favourable micro-climatic conditions for the growth of young plants.

RESTORATION OF OLD SHELTERBELTS

Bringing the depleted and semi-derelict shelterbelts which at present figure prominently amongst farm woodlands into a more useful condition is as important as creating new windbreaks; assuming of course that they are well-sited for modern requirements. There is an endless variety of these old belts; some are more useful than others in abating the wind but all have one common denominator, the urgent need of treatment. In many cases, clearing away the old trees and starting afresh would be simplest; but, wherever they have some small effect on local climate, this is undesirable. Mature trees, however thin on the ground, help to nurse a new crop underneath and offer the benefit of their extra height until the young growth catches up.

Old belts that are lightly stocked, sometimes consisting of little more than a thin scattering of degenerate hardwoods and weather-beaten conifers, are common in upland districts. No underwood halts the wind or tends the soil and invariably the ground vegetation has reverted to grass, heath or moor or a rank growth of weeds on better ground. Most obvious examples are probably the ragged lines of stunted pine and spruce that appear in southern Scotland repeatedly. The first requirement is to attend to drainage, which has often been the root of the trouble. Fences must be put in order. If odd trees only remain, planting can proceed as in the establishment of a new belt. Patches which cast more shade call for a shade-bearing species and if there is a moderate stocking on the ground it is advisable to confine new planting to the more open places, removing the old trees once the second generation is established and contributing useful shelter.

There are other belts which cannot respond to straightforward treatment along these lines; for example, the numerous stands of huge, heavily-crowned beech common in the Lothians. Dense in the crown space and casting a heavy shade, underneath they are bare and incredibly draughty. Yet, they abate the wind somewhat, if at some distance to leeward. Spread widely over a district they make a reduction in the general exposure, as do hedgerow trees. Where a narrower belt is favoured, the new width should be decided upon first of all and marked off from the existing windward edge, which is already well adapted to the wind. After any requisite draining and fencing, some means of blocking out the high winds that funnel between the trunks and render the survival of new plants extremely improbable is of first priority. A screen of small trees and shrubs or fast-growing conifers that keep their branches down to the ground, planted on the windward edge, will do this efficiently. Sitka spruce is generally a safe choice on exposed, reasonably moist upland areas, although it may not be long-lived where the rainfall is below 35–40 in. annually. Scots pine and beech suit many drier areas and lodgepole and mountain pines those that are more difficult and exposed.

Practically nothing succeeds in the dense shade of beech and gaps must be opened in the canopy. Old stems that stand well clear of roads and are expensive to fell can be 'girdled', making a deep axe cut around the trunk; as the supply of water and nutrients is cut off, the tree dies. These scarecrow trees look unsightly for a few years but this is preferable to letting the whole belt gradually decay. New growth springing up below is ample compensation, even to tree lovers. Planting in such situations is best done in groups as large as light conditions allow, new patches being created from time to time and restored. Eventually a new stand evolves to replace the mature beech. It is rarely possible to complete this operation quickly, without very heavy fellings and consequent loss of shelter which it may be affording in the meantime.

Any old trees left on the former leeward part of the belt that is no longer included in the new strip can be gradually removed or retained as park trees for overhead shelter for stock. Alternatively, if they are in sufficient quantity and likely to prove windfirm, they may allow the windward section, which is the part to be restored, to be treated more expeditiously, perhaps even clear-felled and completely replanted.

Whilst Sitka spruce forms an excellent windward edge, as mentioned earlier, it can only be recommended where the interior of the stand is not to consist predominantly of conifers. There are many cases where such margins cannot be replaced without endangering pole stands behind them. As a precaution, it may be better to break up such a margin at intervals with three or four plants of a hardy, permanent species. With many thin and derelict stands, it is often convenient to plant two or three rows of Sitka spruce along the leeward side, where it affords early shelter for stock and crops but can be sacrificed readily when the rest of the stand to windward reaches the required standard.

Some old shelterbelts which have been more or less clear-felled have been invaded by coppice, scrub or sapling growth that has failed to achieve any great height. Complete clearance of such areas is costly and unnecessary. It is generally cheaper to clear groups or lanes that run across the prevailing wind direction. Narrow lanes, 2–3 ft in width, will each accommodate a row of young trees. Alternatively, wider strips that take several rows or scattered groups can be employed. Promising coppice shoots and seedlings can be retained to grow up as standards.

Japanese larch is a particularly valuable species for suppressing undesirable coppice; slower-growing species may require constant attention for a few years to remove competing regrowth.

In a lot of dilapidated belts deterioration started after the wind tore a gap in the line, frequently where drainage was impeded and the choice of species unsuitable. Mending gaps in shelterbelts calls for a quick-growing, wind-resisting selection for the exposed side; Sitka spruce may be appropriate in many cases but alder has the advantage of allowing other species to be introduced below. Alder can be supported behind by spruce in small groups, perhaps with other permanent species in between. Once the wind ceases to rush through the gap one can safely consider less wind-resistant species, for the interior at least. Generally speaking, it is not advisable to use screens like wattle hurdles in order to hasten the process of closing gaps. Young trees easily become conditioned to protection and may not respond when the screens are overtopped or removed. It is better to use a windrow of loose brushwood, enough to shelter newly-planted trees until they have taken root, and thereafter let them adjust to the exposure.

Another class of shelterbelt that often requires rehabilitation, although seldom more than 40 years of age, are the pure conifer blocks and belts which grew well initially but, due to the unsuitability of the site, have begun to deteriorate. Many are in eastern districts, where species more suited to higher-rainfall areas have been planted, Sitka spruce in particular. Difficulty lies in the fact that the belts almost invariably contribute good shelter and their owners are not anxious to dispense with such benefits. Sometimes an adjoining strip can be planted as a replacement, on either the leeward or windward side of the existing belt. In the former position it should incorporate a fair proportion of wind-firm species and could be expected to establish more easily; in the latter, development would be slower but stability should prove greater. Or the leeward half of the present belt might be replaced if the overall width permits and the windward portion thinned out progressively as the new stand develops. The object of the thinning is to accustom the young stand to the wind. The windward half can be underplanted or replanted in groups subsequently, according to the species.

Wherever possible, a new windward row should be established. Sometimes this can be achieved on hill land by moving out a fence two or three yards. Where there are sufficient breaks in the existing windward edge to allow the introduction of small groups of hardy trees and shrubs, these can be a valuable reinforcement. This may be combined in certain circumstances with a series of wedge-shaped fellings, which proceed gradually through to the windward margin from the lee-side. Each year these wedges are increased in area by cutting the edge trees and promptly replanted, using deep-rooting species capable of withstanding the more rigorous conditions once the protection of the windward rows is removed. Storm damage may precipitate the final stages but the method has its value where alternatives are impracticable.

There is a further category of neglected belt, frequently on former farmland that has been absorbed by urban and industrial development, which requires little attention other than fencing and respite from misuse to restore its usefulness.

Every case must naturally be treated upon its own merits since advice cannot cater for all contingencies. Undoubtedly, the most important task in the restoration and rehabilitation of declining shelterbelts is to preserve or create a strong windward margin and especially on exposed sites and difficult soils. Subsequent operations are more simple, straightforward and less expensive. There is also an advantage, from a sheltering point of view, in thickening the leeward edge of open belts.

Protection of Shelterbelts. Young conifers generally face more hazards in their early years than hardwoods. This is true especially when planting occurs on old coniferous sites. Pine weevils and beetles breed in old stumps and emerge to attack young trees, often killing them by girdling the succulent stems near the base. Pine weevil damage can be serious and not long ago it was regarded as essential to leave old sites fallow for four or five years after felling, in order to allow weevil populations to subside to normal levels. Trapping of these insects has tended to be superseded by the use of D.D.T. emulsions, the aerial parts of plants being dipped before planting. Sprays and dusts can be applied afterwards if necessary.

A number of insect pests are liable to attack new plantings but attacks rarely persist and, provided the trees are otherwise healthy and attuned to their environment, the chances of permanent harm being sustained are not great.

Similarly, there are many fungal diseases. Probably most important is the honey fungus, *Armillaria mellea*, attacking the roots of most coniferous and broadleaved species and usually spreading from infected stumps on old woodland sites. It spreads by means of spores and underground threads that look like black bootlaces and are seen frequently under the bark of decaying stumps. Larch and Douglas fir are fairly resistant, as is Norway spruce when young, but Scots and Corsican pines, Sitka spruce and hemlock are very susceptible.

Another fungus causing serious damage in some areas is the heart-rot of conifers, *Fomes annosus*. It may attack young trees, chiefly pines, as a root disease but is most prevalent in later life, often causing the premature felling of trees after 15 to 30 years. It is most common on sites not ideal for the species planted and is frequent on old arable ground and where chalk lies fairly near the surface. Creosoting freshly-cut stumps delays the spread of the disease and hinders its development.

Larch 'die-back' and canker, due to the interaction of frost and a pathogen, *Trichoscyphella* (*Dasyscypha*) *wilkommii*, is encountered in young European larch stands, particularly those planted pure on damp and frosty sites. Selection of more resistant strains, planting on freely-drained soils, avoiding siting plantations so that they block the downward flow of cold air on frosty nights, as well as keeping the interior of a larch belt well ventilated, reduce the incidence and severity of the disease.

Two important bacterial diseases might be mentioned: the watermark disease of cricket-bat willows, *Erwinia salicis*, and poplar canker, *Pseudomonas syringae*. Infected sets appear to have been the cause of the spread of willow disease and any infected trees in willow-growing areas must be felled and burned. The use of more resistant species and varieties of poplars, as a result of intensive research in tree-breeding, is reducing the seriousness of poplar canker.

In all cases where disease or insect attacks call for inquiry or treatment, advice can always be obtained, in Great Britain, from the Forestry Commission; elsewhere, the local forestry or agricultural advisers usually offer a similar service.

In addition, the danger of fire reaching new plantations can never be disregarded. Dry periods when there is an abundance of withered grass on the borders of, and within, plantations and times when moor burning is being carried out constitute the principal hazards. Shelterbelts on hill grazings are often protected by a green, well-grazed strip arising on the margins through constant use by stock. These can be encouraged by liming and fertilisers. Japanese larch is also a valuable species on particularly vulnerable edges. Lastly, elementary safeguards are never wasted.

Perhaps the greatest single threat to the well-being of farm shelterbelts at the present time is the indiscriminate use of chemical weed-killers. Although damage may not prove fatal, scorching or loss of leaves reduces efficiency and, consequently, growth.

11 Shelterbelts and Timber

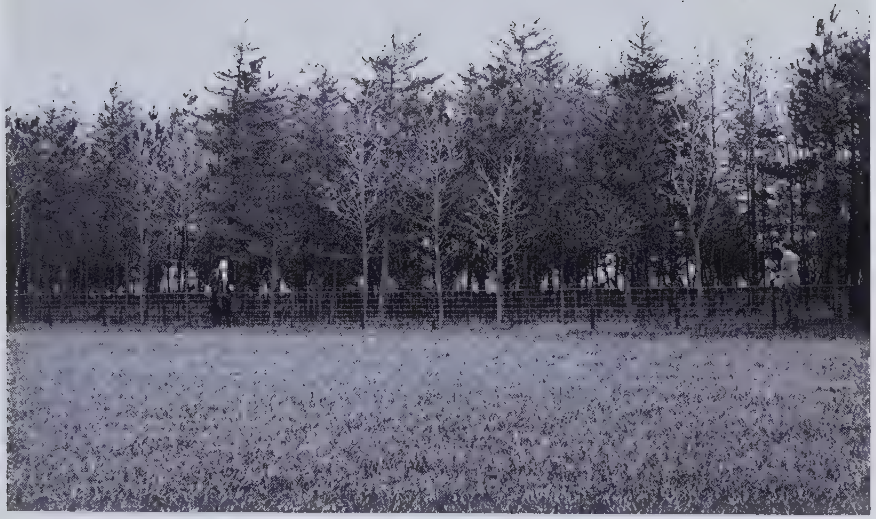
Old shelterbelts and hedgerow trees have provided timber which, bought cheaply because no one reckoned its cost, helped found more than a few timber businesses. Even when the produce is no more than fencing material that can be absorbed on the farm or estate, the prospect of some direct, tangible return makes investment in shelter more attractive. With care and forethought, timber production and wind protection can often be combined successfully. But there are cases where the two interests of shelter and timber conflict with one another.

Narrow belts on agricultural land frequently contain standing volumes per acre higher than those encountered in larger woodlands. On fertile sites where poplars provide protection and timber, volume increment can be rapid, a feature fully exploited in many Continental windbreaks. There are instances on the North Rhine plain where the standing timber, only eight years after planting, has been worth more than the establishment costs. First-class arable land naturally pays better under farm crops than under trees and there is no temptation on such areas to enclose more than the minimum width necessary for shelter; one merely takes advantage of the fact that poplars are good both for narrow windbreaks and quick timber production.

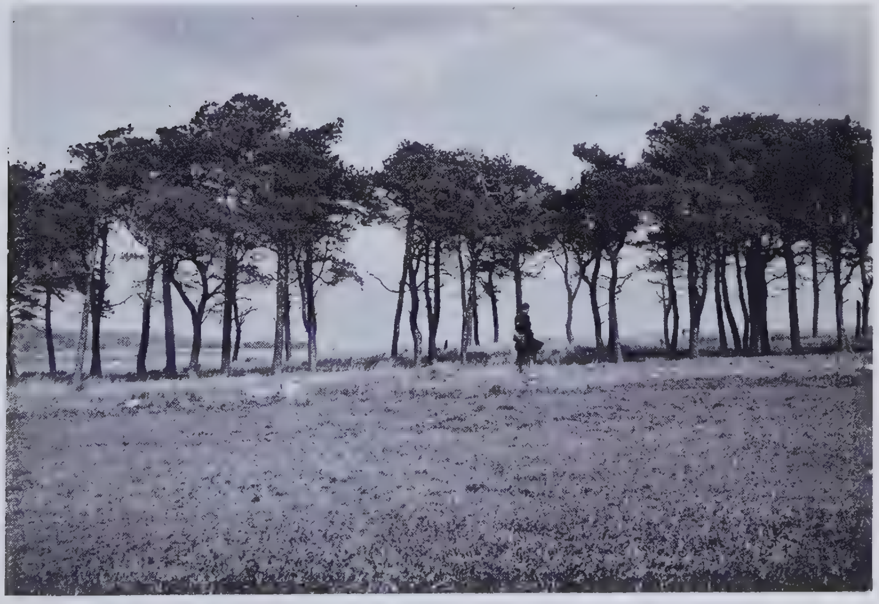
This is a paying proposition but, at the other end of the scale, much rough grazing land lies above the economic planting limit for timber or else cannot be expected to yield more than small quantities of commercial material. Soil conditions, exposure, accessibility and distance from markets restrict the profitable merging of shelter and timber interests on the middle slopes in upland country and on second-class farmland but these are the areas where a successful combination is generally most important, yet not always easy to achieve.

One of the first problems is the question of size and shape for a windbreak. The traditional shelterbelt is a long thin wood, which means more haulage per standard the further one gets from a hard road. Belts that border roads are in a better position, but even then the whole output from a long belt may have to be brought out through one gate, adding greatly to costs. Again, the usual run of belt may not be wide enough for the development of true forest conditions or the production of timber of high-forest quality. But these are secondary to the obstacle of fencing costs. A long shelterbelt, a chain wide, swallows 20 chains of fencing per acre; a mile-long strip consumes 162 chains without allowance for any fenced throughways, as against less than 36 chains for the same eight acres in a square block, which is the cheapest shape to fence. Consequently, there is a tendency for timber-producing belts to be wider or more compact. Provided this is not undesirable from a sheltering aspect, the change is reasonable. Obviously, there must be some sort of compromise and timber prospects should be sufficient to justify the extra ground transferred to trees or economies in fencing should compensate for any restriction of shelter that is involved.

A second problem concerns the selection of species. What grows best for shelter may be uneconomic commercially; conversely, species for quick timber may have little value as permanent shelter. As far as commercial return is concerned, the most economic species is not necessarily the quickest volume producer, although this is usual, nor the one best suited silviculturally to the site, nor the one most readily utilized at home. Farmers like larch but larch on its own is a poor shelterbelt species unless conditions are particularly favourable; it may pay to grow something more appropriate, and with the proceeds buy in better larch than could be grown at home. Local mar-



39 *Farm shelterbelt in East Lothian, formerly moderately dense but pruning of the lower branches has reduced its effectiveness in winter*



40 *Derelict shelterbelt typical of many upland grazing districts in Scotland but capable of improvement*

41 *Mixed farm shelterbelt in process of rehabilitation. A band of Sitka spruce along the leeward side* (right) *will provide early shelter. A hawthorn hedge has been planted on the windward side. Groups of trees are being introduced in the centre and old, thriftless trees removed gradually*

42 *Worn-out shelterbelts can be improved, as a first step, by planting shade-tolerant species in the more open patches. Further groups for replanting can be cleared gradually*

kets are important controlling factors; there is little point, and no profit, in producing turnery material in Scotland, hay poles in East Anglia or rustic larch miles away from a residential centre. A limited demand, coupled with a not over-abundant supply, generally pays well. Larger demands attract the more competitive organization of bigger producers. The choice soon narrows down and the situation still dominates what can be grown at all, or grown to the sawmill size required. For example, useful pioneering species may, on marginal sites, be incapable of achieving large timber dimensions.

The simplest procedure is to prepare a list of timber species suited to the locality, including those which might be grown in limited quantity, such as larch perhaps, and those which might be temporary but capable of reaching merchantable size. Any not likely to find an easy sale should be removed from the list. Special markets can flare up and as quickly die: an unproductive alder carr once brought in handsome returns by meeting a sudden demand for copper refining poles and gnarled and twisted pine windbreaks on Breckland heath have found on occasions a relatively good market when sawn into short boxwood lengths for local customers. But one cannot plan for such outlets. The remaining species can then be assessed on the basis of current timber prices and volume expectations. For the major conifers, Forestry Commission *Management Tables* show the volumes to be expected from the different quality classes of plantation, the particular class being determined on the basis of the height reached within fifty years. Without local evidence from existing plantations it is not easy to forecast the quality class on a particular site and this is where professional advice should help. However, management tables soon reveal that top quality is not everything; an inferior quality class of a more productive species can often be more rewarding in the end.

The productivity of different species cannot, however, be pursued satisfactorily without considering the whole question of shelterbelt management. W. E. Hiley's *Economics of Plantations* shows how profitability depends on the quality of the site, the species selected, the interest rate operating at the time, the choice of a suitable financial rotation and the adoption of different thinning techniques. Such considerations are fundamental in commercial forestry. In the same way, the type, quantity, quality and flow of produce from shelterbelts affect the financial outlook and so influence management over a long period.

Estates with a bias towards forestry or a sawmill as a sideline can absorb the intermittent output from a few belts. Some are rich in shelterbelts, which then become an integral part of a forestry enterprise, although production costs are inescapably higher than where the woodland area is concentrated into bigger parcels. On the other hand, a few farm shelterbelts of limited extent cannot maintain a stream of produce attractive to a timber merchant who has to do his own felling and extraction. The straight division of a shelterbelt in two halves gives a fall of mature timber twice during the prescribed rotation without sacrificing the shelter; but an irregular system of working, whereby removal and replacement are taking place at short intervals, means smaller quantities of timber from each cut, usually of assorted species and sizes, and is less likely to attract a timber contractor. Yet, a farmer who can cut and extract his own produce to the roadside, perhaps during slack periods or wet weather, may find the latter system very suitable. Big trees, however, need big tackle for handling, whereas small timber may pay better because it can be readily extracted. In difficult areas also it may be wise to concentrate on smaller sizes, if saleable, and so shorter rotations. Again, it may be prudent occasionally to clear an upland spruce belt, for example, when it makes pitwood and small sawmill logs rather than risk its being flattened by a gale.

However, an important point to remember is that the area protected by a shelterbelt grows with the trees. Further, the quality of shelter improves as the structure starts to filter the wind. Eventually, an optimum density is attained in all but very wide belts which usually remain dense and impenetrable to wind. From this point, efficiency will decline if the structure thins out with advancing years, which is common in pure conifer strips, and this may occur long before height growth ceases. Similarly, premature cutting can waste years of useful working. Good management should ensure that a shelterbelt reaches its full height, meanwhile maintaining the optimum density at the various levels and especially in the trunk space, and achieves thereby its peak of efficiency. Extending brashing to the outside margins, artificial pruning, heavy thinnings to give good girth increment and major fellings may be suitable for commercial plantations but can be uneconomic in terms of shelter. Light crown thinnings and cautious cutting are more likely to preserve a belt in prime condition for abating the wind.

If there is a temptation to sacrifice the shelter when the timber reaches merchantable size, the advantage of so doing should be weighed against the fact that the stand may just be coming into full efficiency and beginning to repay the years of waiting. Farm woodlands in the past frequently suffered from over-exploitation, only the poorer and less valuable trees having escaped the axe. Draughty belts of heavy, awkward beech, with little or no vegetation beneath, are numerous. Yet, a search amongst the litter or thin cover of Yorkshire fog often reveals the sizeable stumps of larch, pine and silver fir which, in mixture with beech, sheltered fields effectively in bygone years. Farming depressions have seen the best trees go without replacement and left behind the beech, which is invariably a poor substitute for mixed stands that can be a permanent feature. Upland reaches of the country are strewn with signs of former shelter strips and near-useless remnants that are reminders of recessions in agriculture. The breaking up of estates, the separate control of woodland and farmland and the necessities of war have reduced appreciably the shelter established during prosperous periods by earlier generations. But there was no apparent case for preserving shelter when agriculture itself was declining. The real lesson here is not to repeat these mistakes when shelter is needed.

Above all, it is advisable not to lose height when cutting in a shelterbelt. It is easier and usually quicker to fill in the underwood, if this becomes too open after felling operations, than to regain overall height if the tallest trees are removed entirely. The more exposed the situation the more important this is.

Proper wind protection must be catered for if it is going to be efficient and of some value. The same applies to timber production. Coarsely-branched trees stop the wind but make poor timber and in the treatment of belts which combine timber with shelter more attention must naturally be paid to the development of well-formed trees than would be the case in purely sheltering strips. Some lowland strips may be in a position to concentrate on poplars for profit, cutting and replacing a proportion at regular intervals, and using subsidiary species to maintain the shelter. Prompt replacement is essential. Others may grow long-lived, quality hardwoods, perhaps in mixture with quicker volume producers or fuel-wood species. On less fertile and more exposed sites, it may be better to maintain the windward edge as a barrier and to grow timber trees behind. In most cases where the wind has a visible effect on the landscape it is necessary to support productive species with reasonably permanent trees and shrubs selected primarily for shelter. Whether the latter are confined to margins, used in the underwood or in intimate mixture, or form groups or bands through the belt, is a matter for individual decision based largely on site conditions. But the necessity for these subordinate species is evident from past experience; except in a few cases in the lowlands, good shelterbelts are rarely formed from a timber species grown pure.

Shelterbelts are constantly changing in structure and composition and attention from time to time is necessary. Merely maintaining the fences may make a world of difference. But, in addition, there should be some general policy of regenerating the belts, not perhaps a forester's detailed plan of management but a deliberate effort to produce both shelter and timber indefinitely. A belt that is stripped of its worthwhile timber and then allowed to stand idle and inefficient for a number of years is losing money, not making it.

Many farmers with experience of shelter in windy situations would maintain that shelter alone justifies the investment. But the guarantee of a small element of production helps the financial balance. However, production from shelterbelts is rarely of the same order as that from large forests. In commercial enterprises, establishment costs largely govern profitability, in view of the long production period which, taking compound interest into account, swells the original investment alarmingly by the time the timber is ripe for felling. Saving on initial expenses counts: for example, farmland that has been ploughed is cheap to plant and seedlings can often be used instead of dearer transplants. Compared with normal forest units, shelterbelts cost more per acre to establish, chiefly because of small acreages and longer fences. This puts comparatively higher production costs on shelterbelt timber by the end of a rotation, the gap widening as the period lengthens: a £10 saving at the beginning means, at 5 per cent compound interest, an ultimate saving of £304 after 70 years and £1,315 after 100 years.

Against this, shelterbelt planting subsidies (administered by the Ministry of Agriculture for England and Wales and the Department of Agriculture for Scotland) cover a proportion of approved costs and are not paid on an acreage basis, thus reducing the owner's initial outgoings. The grant at present is up to one third of the approved costs.

Clearly, this subsidy has a significant effect on the financial yield later on and usually exceeds that payable by the Forestry Commission for productive planting. The latter is a straight acreage payment however expensive the planting. Consequently, even if a shelterbelt is expected to pay for itself by its timber alone, there is measure of compensation for a lower productivity.

Plantations seldom yield high rates of interest, although fast-growing species on good sites may earn as much as 7 per cent on the investment. Slow-maturing species on poor ground may give less than 2 per cent. Productivity is determined largely by the original state of the soil and atmospheric factors. Unlike farm crops that mature quickly, plantations cannot be boosted artificially to a high level. But, in an economic sense, there are compensations in planting investment, as when the purchasing power of money falls over a long period. Timber planted a century ago commands present prices, not those obtaining when the plantation was established, and this security balances to some degree a lower yield.

Meanwhile, the shelter benefits accruing during the timber rotation cover completely or in part the planting costs and defray interest charges. This contribution varies according to the need for shelter in the first place and the use that is made of the sheltering facilities but even a small annual return from shelter transforms the financial picture mentioned earlier. £10 at 4 per cent becomes £71 after 50 years, £505 after 100 years; at 5 per cent corresponding figures are £115 and £1,315. Thus, if capital for creating a shelterbelt is borrowed at 5 per cent and the shelter value covers as little as 1 per cent, the economic outlook alters remarkably. Better benefits should be obtainable from any planting deserving to be styled a shelterbelt (and subsidized accordingly), so that the necessity of making a shelterbelt pay for itself through production is considerably reduced, if not cancelled completely. Consequently, a shelterbelt that is well-sited to serve the farm and at the same time well-managed to provide useful timber can be a valuable asset and earn fair profits.

12 Farming with Forestry

In Scandinavian countries and parts of continental Europe, forestry is truly the 'handmaid of agriculture', where forestry and farming are so closely interwoven at the farm level that they are no longer separate enterprises but, rather, two branches of a single industry. It would be difficult to envisage the one without the other. The woodlands in fact add stability to the fickle economy of small-scale farming. In the small villages of the Black Forest a typical family farm of perhaps fifty hectares is half under trees. Here, farm forests are the family savings bank, providing dowries for daughters or schooling for sons, assisting the accession of younger generations and the retirement of the old and generally meeting sudden or infrequent demands upon the domestic purse. In the event of a bad year on the farm, they are a source of compensation and a buffer against inflation or deflation. Separation of the two husbandries would be tantamount to strangling the economy of the peasant farm.

Woodlands are part and parcel of the individual farm in more agricultural regions of Germany, if not in such a high proportion. Many farms have fairly large acreages of plantations, sometimes as much as a hundred hectares and exceptionally well-managed, but smaller lots are more common. In one administrative district in Westphalia, 20,000 hectares of woodland are in the hands of 3,500 owners.

Norway and Sweden base their national economies to a large degree on forestry and forest production occupies a key position in the social and economic structure of the community. Yet, more than half the forest land in both countries is owned by farmers and managed by them as part of their farms. Farm forestry in Norway provides between a quarter and a third of the average farming family's total earnings and in the more densely forested parts farmers may make more from trees than from crops and livestock. Smallholders with little or no woodland of their own find casual or regular employment in the surrounding forests a substantial source of income, especially where they have horses for hauling timber.

In other European areas where forestry makes a smaller but still important contribution to the national product, there appears an equally deep-rooted forest consciousness amongst the population as a whole. Farming and forestry are blended in the rural pattern, both have their respective claims as a form of land use and generations have fostered the attitude of partnership. Communal ownership of forests is a regular feature, perhaps seen at its best in the forests owned and managed by the Swiss communes. Farm and woodland co-exist in close harmony. Any grazing practised within the forest boundary is strictly controlled in the general interest and there is no encroachment of the forest on farmland or vice versa. Similarly, partnership prevails in the case of forests owned by the State, although often entailing more tact and skill on the part of professional foresters concerned with woodland management. This applies especially in regions where forest pasturage is customary.

The right to graze animals in the forest may be indispensable to the small farmer; to balance this against the requirements of the forest, without prejudice to either interest, calls for careful administration and control. French and Swiss authorities have devoted considerable attention to this problem, aimed at preserving a healthy relationship between forester and farmer whilst ensuring the continued prosperity of both.

Summer grazing on high mountain tops above the forest is a survival of the age-old practice of transhumance. The advent of summer in the French and Swiss Juras, for example, finds herds of cattle wending their way to the high, gentian-studded pastures where the forests thin out at the natural tree-line. Excellent pasture is afforded in the glades and clearings which break up the forest edge and the scattered trees provide both shelter and shade. Pressure on valley land is relieved and provided there is no regression of the forest limit through overgrazing and subsequent erosion the arrangement is ideal. It is part of the partnership.

The vastly different situation in the British Isles, so near the rest of Europe and separated from it by no more than a narrow strip of water, is surprising. Not only does forestry play a minor role in the national economy but also these two branches of husbandry are widely divorced. The gulf dividing farmer and forester, although lately showing signs of being bridged, is of long standing; the antipathy, if not exactly antagonism, that exists is deeply ingrained and hard to eradicate.

With the exception of Ireland, Britain has the smallest proportion of its land surface under forestry in Europe. Though a forested land originally, a comparatively prosperous agriculture slowly stripped the countryside of its mantle of natural woodlands. Abundant coal removed any need for fuel-wood plantations; the few old copses and remnants of former forest supplied the small materials that were necessary and the development of free trade after the industrial revolution brought in enough imported lumber. Planting on landed estates flourished during the Golden Age and bequeathed bounteous small woods to enrich the landscape and to save the situation during the 1914–18 war. But the urge to plant declined with the delayed effect of the 1846 repeal of the Corn Laws. Competition from New World countries overwhelmed British agriculture, especially in England. There was little money for estate improvement and even less inducement. The decline of planting coincided with the drift from the land.

The depletion of British woodlands, accentuated by wartime fellings, led to the formation of the Forestry Commission in 1919. Faced with a formidable task of afforestation and building up a largish timber reserve against future emergencies, the Commission's path was aside from farming, meeting with the latter only in the competition for land and, occasionally perhaps, for local labour. Thus was perpetuated the quasi-traditional barrier which history had erected. From the first forest laws of King John, which limited access to the forest, through the Middle Ages which transferred control of woodlands largely to the manors, to the enclosure movement and the contraction of the commons, the ways of forest and farmland diverged. Landlords reserved rights to woodland and hedgerow timber and usually to game. The agricultural population had no close interest in forestry and tenants occasionally objected physically to the planting of trees during the fashionable period of estate improvement. To them, planting represented nothing more than a loss of agricultural ground and an intrusion on the part of the landlord. Nevertheless, but for the landlords' enterprise, long stretches of countryside would have remained treeless.

With the rise of State forestry to greater prominence after 1945, controversy increased, chiefly in hill and upland regions. A policy to convert something like three million acres of bare ground to forest within fifty years conjured up visions of wholesale displacement of sheep by trees and large tracts being collared for conifer plantations. This has not proved to be the case. But the vexed question of the future utilization of hill land, the need to rehabilitate areas with dwindling populations and the atmosphere of rivalry between farming and forestry remain.

INTEGRATION OF FARMING AND STATE FORESTRY

The closer integration of agriculture and forestry at a national level was called for in reports by several investigating bodies set up by Government agency. The Report on Mid-Wales (1955) stressed that forestry, properly integrated with farming, would 'strengthen the social and economic fabric of the countryside and assist materially in the rehabilitation of upland areas'. A year earlier, the Report on Crofting Conditions had contained a plea for planting as an adjunct to farming in the crofting areas. These sentiments were reiterated in 1957 by the Natural Resources (Technical) Committee in *Forestry, Agriculture and Marginal Land*, in which it was envisaged that the most remote districts of the country would be given a bias towards forestry, whereas less remote areas would spare land for planting in the shape of steep banks and land not essential for balanced farming units. Smaller areas might also be planted where timber production would be secondary to the provision of shelter, both on high grazings and in valley bottoms. Forestry authorities would be encouraged to plant where shelter could be particularly useful to agriculture.

Benefits would be considerable: shelter would be provided on more farmland, leading to an extended grazing system and a reduction in mortality amongst flocks in winter; timber would be available for farm needs. In addition, sheltered pastures would increase the wintering capacity of hill land, compensating for the area occupied by trees, and therefore effecting an economy in land use. Integration in this sense has been described as 'afforestation aimed at achieving the highest common factor of interests'. In effect, such an intermingling of forestry and agriculture would be similar to that practised on many landed estates for several generations, the principal difference being that farm and forest land would not be in the same ownership. It resembles the arrangement enjoyed by stock-rearers on Germany's Westerwald, where wide shelterbelts, State-owned and managed by the forest service, have been the foundation for the rehabilitation of this once depressed area. Sheltered pastures that meander between the forest belts are owned by individuals and communities, yet there appears to be no hostility between farmers and foresters. The complexity of land ownership has not obstructed Albrecht's century-old improvement plan.

Solid attempts at integration are not often acclaimed but at places like Strath Oykell and Glen Livet in Scotland are impressive. These and other forest and farm figures for Scotland show that increases in the national woodland acreage are not incompatible with increased food production from sheep and cattle. But, in order for integration to be successful, care is necessary in apportioning the land for planting.

A common complaint against forestry in hill-farming circles is that planting shuts off and sterilizes the higher grazings which are unsuitable for trees; or, if access is provided, that there is still insufficient wintering ground at lower elevations for sheep that could use the high tops in summer. When middle slopes are planted, wide 'downfalls' must be left through the plantations for access to summer pastures and there must also be a realistic balance between inbye land and the open hill to maintain the hill farm as an economically viable unit. In addition, since winds tend to be funnelled along valleys, bands of forest along the contour contribute little useful shelter for the low ground. Narrow strips of forest should extend down to the valley level at convenient intervals. To compensate for this extra ground appropriated by trees, the lower forest boundary can retreat farther up the slope or wider downfalls can be left unplanted. Places where canalization of the wind is inevitable have been treated in this way in the partial afforestation of the 3,000-acre hill farm of Watermeetings, at Elvanfoot in Lanarkshire, where plantations are planned to absorb 1,700 acres.

The division of land to serve both interests varies from district to district. In some areas the hill ground is largely planted to productive woodland, whilst farms have shrunk to holdings on the low-lying fields, as at Strathyre in Perthshire. But in too many cases the eventual arrangement has rested on the availability for purchase of land for planting, not the ecological aptitude of land for a particular economic use as conditioned by local climate, soil, situation and relief. Properly planned integration should have an ecological basis. However, there are important implications in this.

Afforestation in smaller units means higher production costs for timber. In addition to greater fencing and operational charges, there will be more forest edges which in exposed areas will be frayed and stunted by the wind, thus lowering the net productive area of forest. The risk of fire spreading through large blocks is reduced but the chance of fire entering the plantations rises as the perimeter increases. On the other hand, amenity considerations may be more readily satisfied and there may be a better distribution of birds and game, although roe deer and hooded crows, for example, are a mixed blessing for neighbouring farmers. But a major advantage falls to the farmer in the form of a reduction in windiness and an ameliorated climate.

Apart from a few isolated examples, however, State-controlled afforestation has not been concerned with shelter for agriculture, as suggested by the Natural Resources or Zuckermann Committee. If this finds official approval in the future, it could be a means of supporting indirectly hill and marginal land development and, in the national interest, should compensate for the lower financial yields implicit in a more scattered form of forestry. It would hardly be consistent with productive forestry aiming at the highest timber return per acre but would recognize that forests have other roles to play, as is the case with protection forests the world over.

FARM FORESTRY

Landed proprietors commonly practise a combination of estate forestry and farming, whether farms are tenanted or in their own hands. Further shelterbelts can usually be absorbed into an existing scheme of working. On the Northumberland hill farm of Emblehope, for example, about 300 acres in eight blocks have been planted for shelter and timber. On an 8,000-acre tenanted hill farm in Dumfriesshire, six plantation blocks of about 70 acres each extend to 1,400 ft above sea level, to give shelter for sheep against the north-easterly exposure in the first place and perhaps cattle eventually. Similarly, at Whitchester in Berwickshire, 700 acres of woodland have improved the 8,000-acre estate which had little shelter against the wind in 1896.

However, these are estates equipped for forestry. Where tenanted farms are equipped with sheltering plantations by landlords who take any timber and relieve the tenants of the responsibility of woodland management, the latter are usually prepared to pay higher rents. Such a practice is traditional and works well in many places. But only when both farmland and woodland are his responsibility does forestry really reach the farmer. Throughout the hilly areas of the country thousands of acres of scrub and open woodland are used, and often highly valued, as wintering ground for livestock. Yet, there are few attempts to perpetuate the woodland and the shelter. Again, numerous strips and neglected woodlands are attached to farms but contribute little to their productivity.

Unaccustomed to such operations as planting and thinning, many farmers fight shy of the experiment. Yet, with the ready advice that is everywhere available, there is nothing in the management of farm woodlots and shelterbelts beyond the capabilities of the average farmer and his labour. In fact, many operations can fit neatly into slack periods on the farm when it is often difficult to maintain gainful employment. In the early stages of establishment of plantations there may be a few problems: planting has generally to be done when there is plenty of other spring work on the land; weeding during the next few seasons may clash with other urgent tasks. But these are rarely insuperable difficulties and forestry operations can usually be done in adverse weather.

Planting shelterbelts by farm labour, even on overtime or piecework rates, as an alternative to bringing in forestry contractors, is not only better for the pocket but also better policy. Pride in workmanship and the wish to see the fruits of one's labour invariably mean that an interest is taken in the trees afterwards. There is a far better chance of the odd rabbit being removed, pests spotted promptly and young trees saved from smothering grass than when the work is of no concern to the regular farm staff. To illustrate this point, two derelict shelterbelts were replanted by outside labour on a West Lothian farm but subsequently failed. Five years later, fences were repaired and the whole replanted by a cattleman and tractor driver without previous experience of planting trees. The second replanting got off to a flying start and interest, once generated, ensured no difficulties over weeding. A third belt, planted the following year, was similarly successful.

GRANTS AND ALLOWANCES

Planting can be fairly expensive and, in order to encourage the establishment of farm shelterbelts, certain grants are available from Government sources. The Agricultural Act (1957) provides shelterbelt grants for all farmland satisfying certain basic conditions, the provision of belts being scheduled as one of many improvements likely to attract a grant of one-third of approved costs. These schemes are administered by the Ministry of Agriculture in England and Wales and the Department of Agriculture for Scotland.

Alternatively, shelterbelts more than one acre in area may be eligible for a Forestry Commission grant for the planting of small woodlands, provided timber production is a main object and that planting and maintenance are carried out to the Commission's satisfaction. This grant is paid on an acreage basis and does not apply to plantations intended only for shelter.

As regards taxation, the owner or tenant of agricultural or forestry land is entitled to claim certain income tax allowances in respect of capital expenditure incurred in creating shelterbelts, excepting expenditure that could be included in a maintenance claim. Where subsidies towards total costs have been received from public funds, only the net outlay qualifies for the allowance.

Woodlands are generally assessed for income tax purposes under Schedule B as regards occupation; but, since shelterbelts on agricultural land are normally considered an integral part of the farm, no separate assessment under Schedule B is normally required. Where shelterbelts were not planted with the intention of timber production on a commercial basis or of clear felling at maturity, the disposal of thinnings and mature trees removed in the course of management may be regarded as the dispersal of a capital asset. Since the proceeds are not considered to represent taxable income, the costs of felling, disposal and replanting cannot be charged against revenue. Any receipts from other sales of produce from farm belts can be regarded as normal farm receipts.

Woodlands which have to be assessed under Schedule B because they are not planted and maintained primarily for shelter to farm land have a gross assessment equivalent to one-third of their annual value. If the woods are managed on a commercial basis, an allowance in respect of earned income may be due. No relief is allowed, however, if the net profit from the woods happens to be less than the assessment or if the woodland account actually sustains a loss. Owners or occupiers of woodlands, who satisfy the tax commissioners that the woodlands are being managed on a commercial basis with a view to profit, may elect to be assessed under Schedule D, i.e. on the actual profits, rather than Schedule B. Such a situation may arise where shelterbelts are a small part of the total woodlands on an estate and are included for convenience with them.

In the case of death duties, special features apply to woodlands. Estate duty is paid at the time of death on the land value and the amenity value of timber, trees and woods. The commercial value of such timber is not subject to duty until such time as it is realized by sale or felling.*

* Further information is contained in Forestry Commission Leaflet No. 12, *Income Tax and Estate Duty on Woodlands,* H.M. Stationery Office.

43 *Well-grown pine shelterbelt on upland boulder till, part of a valuable network of belts on Cockdurno Farm, Balerno, Midlothian*

44 *Forestry in a Perthshire landscape contributing shelter, timber and amenity*

45 *Integration of farming with forestry, Glenlivet. Young pine shelterbelt in the foreground; Cnoc Fergan and Ballantruan woods beyond the agricultural land*

46 *Plantations for shelter and timber, Cranshaws Farm, Whitchester, Berwickshire*

THE FINANCIAL OUTLOOK

The cost of establishing shelterbelts varies throughout the country, due chiefly to the nature of the ground. Similarly, conditions of climate and situation determine the direct and indirect influences of sheltering plantations on farm income. Consequently, there are limitations inherent in any attempt to suggest the average net return to be obtained from planting shelterbelts.

On the debit side, there are clear-cut costs of ground preparation, fencing, draining, planting, replacing any failures, and weeding, which together constitute the costs of establishment. In addition, there is an annually recurring charge in respect of the rental value of land occupied by shelterbelts; on good arable ground this is obviously significant. In due course, costs of cleaning and other maintenance can be added. Later treatment may largely pay for itself in the form of thinnings or mature trees felled and these are entitled to be costed even if used at home. Any surplus from sales becomes a credit entry.

On the credit side are the direct financial returns, in the form of usable or saleable produce, planting grants and taxation benefits, and the indirect values represented mainly by shelter.

Indirect values are generally glossed over, although automatically represented in the market price of farms and estates. The presence of plantations frequently puts up the price of a property more than their realizable value warrants. Naturally, amenity value is included and though irritatingly indeterminate is not to be ignored.

The value of shelter can be measured in terms of animal and crop responses to shelter but not without difficulty. Changes in the yield of arable crops grown within the influence of shelterbelts may be apparent or may be obscured by rotations, the introduction of new varieties and improved cultural techniques. A simple comparison of yields with past averages is not usually sufficient; intensive sampling becomes necessary to obtain a reliable measure of shelter effect. Recent Swedish research, based on several years' study of different crops, considers the average yield increase due to shelter to be of the order of 6 per cent. This figure provides a useful guide. But the benefit of wind protection may be more in the nature of better germination, earlier ripening, reduction of the wind's physical action or safeguarding the soil against erosion, which do not permit a ready assessment.

In the case of livestock farming, where the output is in terms of meat and milk or probably lambs and wool, an estimate of shelter value is often more elusive, especially over short periods. Such points as early growth of grass near trees or longer grazing periods on hill ground have a market value, which only experience can assess. Appreciable reliance must continue to be placed on fundamental investigations concerning the effect of exposure on livestock. As a result of studies in nutritional physiology, Dr K. L. Blaxter of the Hannah Dairy Research Institute calculated in 1961 that to maintain a 1 lb daily gain in bullocks under average Scottish weather entailed spending about 18*s* more on food per head per year than would be the case if the cattle were housed in a simple shed. Hoggets over an average winter required about 2*s* worth of extra food per head. Efficient windbreaks would presumably meet a proportion of this extra expense but it is too early to say how much. More research is urgently needed.

In most cases, a fairly reliable indicator is the long-term trend in farm productivity and income. Shelter's contribution frequently depends upon the way in which its benefits are utilized within a system of farm management, and this should be revealed over a long period. In practice, however, it becomes increasingly difficult with time to dissociate the influences of shelter, which are cumulative in themselves, from other improvements. Dr S. E. A. Landale has attempted this for a high-lying farm on his Whitchester estate in Berwickshire by comparing 1896 stock values (adjusted to 1960 levels) with those in 1960. During this period the farm gradually acquired a number of shelter plantations. He shows a more than twofold increase in productivity over this period and suggests that a quarter to a third of the total improvement might reasonably be attributed to shelter. This is a 30–40 per cent increase. Critical though one might be of such estimates, they have as their basis many facts which farmers understand, even if they defy simple expression in cash terms: ewe hoggs wintering at home rather than away; earlier lambing and calving being practised with fewer losses; heavier North Country Cheviots having replaced Hill Cheviots on the lower ground. Just as the enclosure of land from the fifteenth century onwards gave an advantage to agriculture that could hardly be measured over one or two generations, the provision of shelterbelts appears to work similarly.

Appendix

Key to the Selection of Tree Species

FERTILE SITES

WET	Deep, rich, very moist alluvium and fenland, mostly cultivated; perhaps with wet depressions carrying alder, reeds and tussocks of *Molinia.*	Hybrid poplars; common alder; common, cricket-bat and crack willows; Norway spruce (with nurse).
	Heavy, wet, compacted silts; limestone clays; low-lying, highly fertile, calcareous soils in damp districts.	Alder; ash; grey poplar; Norway and Sitka spruce; western red cedar.
	Wet clay patches on fertile hill ground, often carrying *Carex* spp.	Alder; willow; Norway spruce; western red cedar (with nurse).
	Loose peat in wet hollows, dominated by soft rushes.	Alder; poplars; Norway spruce or Sitka spruce if exposed.
MOIST	Fertile, base-rich boulder till in valleys and on lower slopes; generally good agricultural land.	Ash; sycamore; elms; grey poplar; common and grey alder; horse chestnut; hornbeam; lime; field maple; walnut (if not cold); Lawson cypress; western red cedar.
	Good drift soils of central England; heavy loams, clays and marls; valley bottoms of Silurian and Carboniferous limestone formations.	Oak; Turkey oak; horse chestnut; hornbeam; lime; scarlet oak; Norway maple; Japanese larch; Norway and Sitka spruce; Scots pine (East England); Corsican pine (dry districts).

	Steep, fertile, rocky slopes carrying abundant ferns; deep fertile, non-alkaline soils; loose sand and gravel or colluvial material over boulder till in valleys.	European larch; Scots pine; Douglas fir; Norway spruce; Lawson cypress; western hemlock; silver fir; beech; hazel; alder, birch, pine, larch as nurses; wild cherry; sweet chestnut on lighter soils.
	Fertile rocky slopes at elevations too high for oak and ash, often bracken-covered.	Sitka and Norway spruce; European larch.
DRY	Chalk downs; limestone hills in low rainfall districts with grass and lime-loving herbs.	Austrian, Corsican and Scots pine; birch; lime; wych elm; whitebeam; horse chestnut; cordate-leaved alder; beech (with nurse); European larch as a nurse species.
	Shallow calcareous soils of Wolds, Derbyshire limestone, etc.	Japanese larch; Corsican pine; wych elm; birch; beech and ash (with nurses); Norway maple; Turkey oak; hawthorn; *Prunus* spp.
	Sands over chalk and limestone in south and east.	Corsican and Austrian pine (latter for shallower soils); western red cedar.
	Dry slopes on limestone and similar formations in high rainfall areas from North-west England to North Scotland, perhaps with scrub woodland of ash and birch.	European and Japanese larch; Douglas fir; birch; rowan.

MODERATELY FERTILE SITES

WET	Relatively rich flushes with shallow peat.	Norway spruce; alder; sallow.
	Shallow *Molinia* peat, usually over heavy clay soils.	Norway and Sitka spruce; western red cedar; alder; aspen; sallow.
MOIST	Heavy, impervious, slightly acid soils; heavy glacial tills over coal measures, Silurian and other sedimentary rocks yielding clays; no peat present.	Sessile oak (with nurse); alder and birch as nurse spp.; Sitka and Norway spruce; Scots pine; western red cedar and western hemlock for underplanting.
DRY	Well-drained loams; light sands and gravels in low rainfall areas of South-east and East England and East Scotland; well-drained rocky slopes in higher rainfall districts; dry oakwood areas, perhaps with oak scrub; dry porous soils of moderate fertility; knolls and slopes without glacial deposits; Silurian formations in Wales, Ireland and South-west Scotland.	Japanese and European larch (Japanese replaces European in south); Douglas fir; Scots pine; Corsican pine on light soils in south and east.

INFERTILE SITES

WET	Leached peat soils on Silurian schistose and limestone hills, often dominated by *Eriophorum*, possibly with *Molinia* and *Juncus squarrosus*.	Sitka spruce (on turf); common alder; common birch.
	Fibrous peat dominated by *Eriophorum* with *Calluna* and *Trichophorum* present.	Sitka spruce (on turf) with lodgepole pine as nurse; apply phosphate.

	Fibrous peat moorland dominated by *Calluna* and *Sphagnum* moss with *Trichophorum* and *Molinia* present.	Lodgepole pine (after cultivation and manuring).
	Moderately deep, fibrous peat dominated by *Myrica* associated with *Calluna*, *Molinia* and *Eriophorum*.	Sitka spruce with nurse crop of common birch, common alder or lodgepole pine; apply phosphates.
	Pseudo-fibrous peat dominated by *Trichophorum* and *Calluna*	Sitka spruce with lodgepole pine; possibly some Japanese or hybrid larch.
	Waterlogged areas carrying a quantity of *Erica tetralix*.	Lodgepole pine.
	Dark brown or black amorphous peat dominated by *Molinia*.	Sitka and Norway spruce (on turf).
	Amorphous peat dominated by *Molinia* but with a proportion of *Calluna*, *Trichophorum* and *Vaccinium*.	Sitka spruce with lodgepole pine in mixture if exposed or Scots pine if not too exposed; Japanese larch may replace Scots pine if peat is thin.
	Sphagnum moss dominant in large tussocks.	Unplantable
MOIST	Shallow, acid, peaty areas dominated by *Nardus* and *Molinia* with *Juncus squarrosus*.	Sitka spruce; Norway spruce; Scots pine; western red cedar (with nurse); noble fir.
	Morainic mound terrain and rock areas dominated by *Vaccinium* with some *Calluna*; leached siliceous soils even at low elevations.	Scots pine; lodgepole pine; birch; rowan.
	Birch scrub areas with ground vegetation of *Vaccinium* or grass/herbs in wetter, western districts.	Sitka spruce; Douglas fir in hollows; Scots pine on mounds.

MOIST	Bare exposed moorland over heavier, moist, impervious soils dominated by *Erica tetralix* and *Calluna* with *Trichophorum*.	Lodgepole and mountain pines; Scots pine possible if ploughed and phosphate applied; common birch.
	Knolls carrying *Trichophorum* and *Calluna*.	Lodgepole pine.
DRY	Siliceous glacial sands and gravels of drier districts of East Scotland, probably supporting a good deal of *Vaccinium*.	Scots pine with little European or Japanese larch; small quantities of Douglas fir in sheltered spots.
	Dry heathland with predominance of *Erica cinerea* mixed with *Calluna* and fine heath grasses.	Scots pine in north; Corsican pine in south.
	Sandy, acid or gravelly ground of low fertility.	Scots and Austrian pines; maritime pine on deep sands in south and west; western hemlock; birch; red oak.
	Calluna heath with layer of mosses (not *Sphagnum*); typical grouse moor of north and often periodically burned.	Scots pine; birch; red oak.
	Morainic knolls with *Calluna* and thin peat and locally dry conditions.	Scots pine; Japanese larch.
	Bare, infertile and dry ridges and knolls on granitic or leached sandstone soils, often with stunted *Calluna* and dense lichen layer beneath; frequently overburned areas.	Lodgepole and mountain pines; Scots pine possible if ground well prepared.

NOTE:—Indicator plants are particularly important in the selection of species for moorland and heathland sites. The common names of those mentioned in the above key are as follows:

Key to the Selection of Tree Species

Calluna vulgaris	Ling, Heather
Carex spp.	Sedges
Erica cinerea	Bell-heather
Erica tetralix	Cross-leaved heath
Eriophorum spp.	Cotton-grass
Juncus squarrosus	Heath rush
Molinia caerulea	Purple moor-grass
Myrica gale	Bog-myrtle
Nardus stricta	Mat-grass
Sphagnum spp.	Sphagnum mosses
Trichophorum caespitosum	Deer-grass
Vaccinium myrtillus	Bilberry, Blaeberry
Vaccinium vitis-idaea	Cowberry

PLANT REQUIREMENTS PER ACRE

SQUARE PLANTING		RECTANGULAR PLANTING		TRIANGULAR PLANTING*	
Spacing ft	*Trees No.*	*Spacing ft*	*Trees No.*	*Spacing ft*	*Trees No.*
2	10,890	2 × 3	7,260	2	12,578
3	4,840	3 × 4	3,630	3	5,590
3½	3,555	3 × 5	2,904	3½	4,106
4	2,722	4 × 5	2,178	4	3,144
4½	2,151	4 × 6	1,815	4½	2,484
5	1,742	5 × 6	1,452	5	2,012
5½	1,440	5 × 7	1,244	5½	1,663
6	1,210	6 × 7	1,037	6	1,398
7	889	6 × 8	908	7	1,026
8	680	7 × 8	778	8	785
9	537	8 × 9	605	9	620
10	435	9 × 10	484	10	502
15	193	10 × 15	291	15	223
20	109	15 × 20	146	20	125

* Trees equidistant from neighbours in the same and adjoining rows; therefore rows must be nearer. The distance between rows can be calculated as follows:

Distance between rows = $\sqrt{s^2 - \left(\frac{s}{2}\right)^2}$ where s = distance between plants

NOTES

Hogg, hogget	a yearling sheep
Policy, -ies (*Scot.*)	grounds around a mansion
Stell (*Scot.*)	an enclosure for sheltering sheep

1 chain = 22 yards
1 rod = 5½ yards
1 hectare = 2.47 acres

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Index

Abies, see Silver Fir
Acer, see Maple and Sycamore
Aesculus, see Chestnut, Horse
Alder, 122, 153, 156, 173, 175, 182, 183, 188, 192, 195, 198, 206, 208, 211, 230, 231, 251, 276; cut-leaved, 184
Alnus, see Alder
Armillaria, 253
Ash, 117, 155, 172, 173, 183, 187, 188, 192, 198, 208, 211, 214, 215, 220, 243, 246
Ash, Mountain, *see* Rowan
Aspen, 125, 175, 195
Atmospheric pollution, 60, 182–4, 198
Atriplex, 160, 173
Aucuba, 174, 182
Avenues, 151–2, 176–7; windiness of, 58–9

Beech, 116, 153, 154, 155, 158, 173, 183, 184, 187, 188, 192, 209, 214, 215, 228, 229, 232, 246, 249; copper, 116; fern-leaved, 116, 184; hedges, 39, 147; screens, 149

Berberis, 147, 160, 174, 181, 182, 186, 198
Betula, see Birch
Birch, 123, 155, 156, 158, 160, 173, 175, 182, 183, 187, 188, 192, 195, 198, 211, 214
Birds, in shelterbelts, 83
Blackberry windbreaks, 53–4, 146, 190–1
Blackthorn, 127, 147, 174, 181, 187, 246
Blocks, shelter, 99, 100, 223–5
Botrytis, 186
Box, 127
Broadleaved trees, descriptions of, 114–36
Broom, 127–8, 147, 174, 175, 187
Buckthorn, Common, 128
Buckthorn, Sea, 82, 128, 172, 173, 175
Buddleia, 174, 182
Bullace, 128
Buxus, see Box

Caragana, 192, 206
Carpinus, see Hornbeam
Castanea, see Chestnut, Sweet
Cedar, Incense, 114; Japanese, 113, 151, 160; Pencil, 113, 151; Western Red, *see Thuja*
Chamaecyparis lawsoniana, see Cypress, Lawson; *nootkatensis*, 111, 151; *obtusa*, 111, 151; *pisifera*, 111, 151
Cherry, Bird, 129, 187; Rum, 129, 187, 218; Wild, 129, 158, 187; *see also* Myrobalan
Chestnut, Horse, 121, 155, 157, 182, 183, 184, 186, 187, 198, 228; Spanish or Sweet, 119, 153, 208, 211, 214; pleached, 148
Climate, improvement of, 25–6
Clumps, for parks, 177–82
Coastal sands, 82, 175
Coastal situations, windbreaks for, 166–75
Conifers, descriptions of, 103–13
Cornus, 130, 160, 174, 198, 247
Corylus, see Hazel
Cotoneaster, 128, 147, 174, 182, 187, 198
Cottonwoods, *see* Poplar
Crab, 129, 155, 158, 198
Crataegus, see Hawthorn
Cryptomeria, 113, 151, 160
Cupressocyparis leylandii, 112, 150, 171, 188
Cupressus macrocarpa, see Cypress, Monterey
Cypress, 111–2, 147, 150–1, 158, 160, 206, 208; Lawson, 111, 183, 188, 206, 237; Leyland, 112, 150, 171, 188; Monterey, 111, 150, 151, 168, 170, 183, 188; Nootka, 111, 151
Cytisus, see Broom

Deciduous trees, descriptions of, 105–6, 114–36
Density, of windbreaks, 31–6, 62–4, 84, 144–5, 158, 170, 189–90, 205–6, 226–7; optimum, 35–6
Derelict shelterbelts, restoration of, 248–54
Designs, planting, 137–65, 215–22
Diseases, orchard and nursery, 53, 186–8; farm crop, 84; tree, 252–4
Dogwood, *see Cornus*
Douglas Fir, 108–9, 183, 214, 215, 231, 243, 246, 253, 277–80
Duty, Estate, 272

Eddying, 31, 38, 45, 84, 138, 201
Elder, 130, 147, 169, 174, 198
Elm, 119–20, 147, 153, 154, 155, 172, 182, 183, 187, 188, 198, 208, 214, 215; Cornish, 120, 172; English, 119; Guernsey, 120, 172; Huntingdon, 119; Jersey, 120; Wych, 119, 172
Erosion, 27, 81–2, 204
Escallonia, 45, 49, 147, 160, 168, 174, 184
Estates, shelter for, 64–70; and timber, 258; duty, 272
Euonymus, 134–5, 173
Evaporation, 49–50
Evergreens, 145, 147, 151, 154, 158, 186
Exposed situations, 67, 149, 157, 170, 186, 209, 227; planting in, 161–2; on coasts, 166–75
Exposure, 18, 24, 85, 89, 140, 170

Fagus, see Beech
Failures, replacing, 240
Farm forestry, 263–6, 269–70

Index

Farm shelterbelts, 199–241
Fences, 145–6, 168, 178, 186; deer, 235; rabbit proof, 235; snow, 60–2, 64, 192–3
Fencing, costs of, 178, 226, 256; practice, 234–6
Field Maple, 118, 147, 153
Fomes, 253
Forsythia, 184
Fraxinus, see Ash
Frictional drag, 29–30, 167, 201
Frost, 21, 36, 46–8, 143, 186; in shelter, 46, 143–4; on roads, 196; pockets, 21, 47, 253; wind, 36, 48
Fuel consumption, 39–40
Fungal diseases, 53, 84, 186–8, 252–4
Furze, *see* Gorse

Gales, 17, 18, 38–9, 137, 139, 168, 169
Gaps, in belts, 202–3
Gean, 129, 158, 187
Gorse, 130, 174
Grants, planting, 271–2
Greenhouses, 40; shading of, 41–3
Griselinia, 173, 184
Group planting, 160, 179–80, 220–2, 229–31
Growing season, 72–4
Growth, rates of, 214
Guelder Rose, 130
Gusts, 20, 60, 137, 191

Hawthorn, 131, 147, 173, 181, 187, 198, 208, 211, 220, 228
Hazel, 131, 147, 153, 186, 187, 208, 211, 214, 246
Heat loss, 39–40
Hedgerows, 66, 72, 153, 201, 208, 227
Hedges, 22, 39, 45, 49, 54, 68, 82, 83, 93, 146–8, 153, 158, 160, 174, 186, 187, 192–3, 202, 206, 211; planting, 146–7
Height, effect of, 33–4; planning for, 150, 210
Hemlock, 112–3, 151, 207, 214, 231, 246, 253
Hill farm shelterbelts, 222–31
Hippophae, see Buckthorn, Sea
Holly, 131, 147, 154, 160, 182, 184, 198, 246
Honey Fungus, 253
Honeysuckle, 131, 147, 154
Hornbeam, 120, 147, 153, 154, 155, 156, 158, 173, 183, 188, 198, 207, 211, 214, 246; hedges, 39; pleached, 149
Humidity, in shelter, 37
Hydrangea, 184
Hypericum, 184

Ilex, see Holly
Indicator plants, 280–1
Integration, of farming and forestry, 266–9

Juglans, see Walnut
Juniper, 102, 114, 160, 174, 183, 187
Juniperus virginiana, 113, 151

Laburnum, 132, 158, 174, 187
Landscape, effect on wind, 29–30
Landscaping, 64–5, 177–8
Larch, 105–7, 151, 187, 214, 215, 243; 246, 253; canker, 253; European, 64, 105–6, 214, 220; Hybrid, 106, 231; Japanese, 106, 183, 193, 214, 229, 231, 251, 254, 276–80; Siberian, 107, 219
Laurel, 132, 147, 154, 187, 198, 228, 247
Layout of shelterbelts, 200–5
Leaf fall, in parks, 182
Length of shelterbelts, 200
Libocedrus, 114
Light requirements, 164, 214
Ligustrum, see Privet
Lilac, 132, 184, 187
Lime, 59, 120–1, 153, 157, 182, 183, 188, 198, 207, 211, 228, 246; avenues, 177; pleached, 148–9
Liriodendron, 184
Livestock, 69, 85–99; diseases and shelter, 88–9, 96; outwintering, 95
Lonicera, 131, 160, 174, 187
Lowland farm shelterbelts, 200–22
Lycium, 135, 154, 169, 172

Maintenance, clumps, 181–2; shelterbelts, 242–8; small windbreaks, 161–5
Malus, see Crab
Manuring, 161, 239

Maple, 64, 117–8, 183, 192, 198, 208; Field, 118, 147, 153; Norway, 118, 155, 173, 214, 219, 246; ornamental, 118, 160
Market gardens, 24, 44–5, 50–5; windbreaks for, 185–91
Markets, timber, 256–7
Margins, wind-firm, 228
Micro-climate, 27, 30, 36–7, 52, 74
Mixtures of species, multiple-row windbreaks, 157, 173, 179–80, 213–22, 228–9; single-row windbreaks, 152, 154
Mountain Ash, *see* Rowan
Mulching, 147, 163, 239–40
Multiple-row shelterbelts, 156–60, 169–70, 189, 209–22, 227–31
Myrobalan, 132, 147, 160, 188, 198

Notch planting, 233, 237–8
Nurseries, 24; windbreaks for, 185–91

Oak, 114–6, 156, 160, 173, 182, 184, 198, 211, 214, 215, 230, 232, 246; evergreen, holm, 116, 173; pedunculate, 114, 218; red, 115, 184, 218; scarlet, 115, 184; sessile, 114–5, 173, 228; Turkey, 115, 173, 183
Olearia, 160, 168, 174
Orchards, 24, 49, 52–3; windbreaks for, 185–91
Ordering plants, 236–7
Orientation of windbreaks, 200
Ornamentals, 150–1, 158–60, 184

Paddocks, hill, 93, 225–6
Pasture, effect of shelter on, 72, 80, 90–1; in forests, 92
Pear, 133, 155, 173, 183
Permeability of windbreaks, 167, 205–6, 245–6
Pests, farm crop, 84; horticultural, 53; nursery and orchard, 186–8; shelterbelt, 252–4
Philadelphus, 147, 182
Picea, see Spruce
Pine, 103–5, 171, 175, 192, 198, 208, 214, 215; Aleppo, 171; Austrian, 104, 151, 171, 183, 214; Bishop, 171; Black, 171; Corsican, 104, 171, 188, 209, 214, 218, 231, 253; Lodgepole, 104–5, 170–1, 195, 214, 228, 231, 249, 253; Maritime, 105, 171; Monterey, 105, 171; Mountain, 105, 171, 195, 228, 249; Scots, 102, 103–4, 151, 152, 171, 187, 188, 195, 209, 213, 214, 218, 219, 220, 229, 231, 243, 249, 253
Pinus, see Pine
Pittosporum, 49, 168, 174, 186, 187
Plane, Corstorphine, 118, 184; London, 149, 183, 187
Plant requirements, 229, 231–2; table of, 281
Plants, size of, 167, 236
Planting, designs, 216–22; distance, 155, 157, 164–5; hedges, 146–7; historical, 64–7, 265–6; methods, 161, 237–9; practice, 231–41; roadside, 191–8; screens, 148–9; seaside, 166–75; season, 147, 163, 237; small windbreaks, 161–5; time of, 237; turf, 233, 238
Pleached screens, 148–9, 164
Ploughing, 233–4
Policies, 151, 281
Polygonum, 146
Poplars, 124–6, 183, 187, 205, 207, 209, 210, 214, 219, 255; balsam, 126, 208; black, 125, 190; canker, 253–4; grey, 125, 172; hybrids, 126, 172, 188, 208, 214, 276; Lombardy, 126, 154, 188; planting schemes, 217; pruning, 247; root spread, 153, 156, 198; single-row windbreaks, 153, 164, 188; spacing, 231; white, 125, 169
Potentilla, 160
Preparation of ground, 161, 232–6; coastal sands, 175
Privet, 133, 147, 154, 160, 187, 247
Profile, cross-sectional, 167, 205, 210; irregular, 206–7
Protection of shelterbelts, 252–4
Pruning, 59, 144, 163–5; clumps, 181–2; hedges, 147–8; screens, 148–9, 153, 155, 190; shelterbelts, 247
Prunus, 145; *avium*, 129, 158, 187; *cerasifera*, 132, 147, 160, 188, 198; *insititia*, 128; *laurocerasus*, 132; *lusitanica*, 132; *padus*, 129, 187; *serotina*, 129, 187, 218; *spinosa*, 127, 147, 174, 181, 187, 246

Pseudotsuga, see Douglas Fir
Public parks, 56–60, 175–85
Pure and mixed stands, 213–5
Pyrus, 133, 155, 160, 173, 183

Quercus, see Oak

Radiation, outgoing, 46–8, 90, 143, 186
Railways, 60–4, 191–8
Rainfall and forests, 26–7
Recreation grounds, 56–60, 175–85
Redwoods, 113; in avenues, 177
Regeneration, 247–8
Replanting gaps, 158
Restoration of shelterbelts, 248–52
Retinospora, 111
Rhamnus, 128
Rhododendron, 133, 147, 154, 182, 198, 228
Rhus, 160
Ribes, 182, 198
Roads, 60–4, 180, 191–8
Robinia, 181, 184, 211
Root robbery, 141, 156; avoiding, 201
Roots, care of, 162; growth, 163; spread, 153, 156, 198, 201, 204–5
Roses, 133, 146, 174, 175, 181, 184, 187
Rowan, 134, 153, 155, 158, 173, 187, 198, 218, 228
Rubus, 169, 187, 247

Salix, see Willow
Salmonberry, 169
Salt spray, effect on plants, 18, 24, 44, 168, 172; resistance to, 170–5
Sambucus, see Elder
Sands, improvement of, 175
Sarothamnus, see Broom
Screens, pleached, 148–9; tree, 175, 176
Seaside situations, windbreaks for, 166–75
Senecio, 160, 174
Sequoia, 113, 152, 177
Service, Wild, 134
Shade, 155–6, 157, 165, 249; tolerance of, 152, 154–5, 214, 215, 244–5, 246–7
Shading, by windbreaks, 41–3, 45, 54, 196; avoiding, 137, 139–42, 197, 201
Shadow length, 41–3
Shelter, 22, 24, 27–8, 67–9; effect on ripening, 40, 51; effect on yields, 51–4, 75–81, 87, 274; 'natural', 96–7, 98, 138, 222–3
Shelterbelts, American, 179, 211, 218; farm, 200–30; parallel, effect of, 28; planning, 229–30; Russian, 211, 218, 219
Shrubberies, 148
Shrubs, covert, 215, 217, 246–7; for margins, 182; for roadsides, 198; for snow traps, 192; for town planting, 184; for underwood, 155, 158, 211, 215, 216
Silver Fir, 64, 109–10, 156, 172, 195, 214, 215, 229, 246
Single-row windbreaks, 149–56, 173, 206–9
Sites, classification of, 276–80
Skimmia, 160
Smoke, resistance to, 60, 183–4
Snow damage, 194–5; drifting, 37, 61–4, 77, 97, 192–7, 202, 224; fences, 52, 60–2, 192–3; and livestock, 89–90, 97
Snowberry, 134
Snowy Mespilus, 134
Sorbus, 134, 135, 145, 160, 173; *see also* Rowan, Whitebeam
Spacing, of trees, 155, 157, 208, 209, 218, 231; of windbreaks, 189–90, 202, 203–4
Species, choice of, 59–60, 101–3, 178–9, 276–81; for farms, 206–9, 210, 215–22; for nurseries and orchards, 186–91; for parks, 178–81; for roads, 197–8; for seaside situations, 169–74; for small windbreaks, 149–60; for timber, 256–7; for towns, 182–5
Spindle Tree, 134
Spiraea, 135
Spruce, 107–8, 151, 156, 158, 187, 188, 192, 195, 206, 215, 246, 251, 253; Norway, 107, 151, 206, 208, 213, 214, 231, 253; Serbian, 108; Sitka, 107, 151, 172, 206, 209, 214, 229, 249, 250, 251; white, 108, 206, 208, 229

Stell, 89, 99, 100, 281
Storage of plants, 163
Strip cropping, 54, 186
Structure of shelterbelts, 158, 165, 193–4; *see also* Density
Subsidies for planting, 261
Sunshine, in Britain, 56–7
Sycamore, 117–8, 155, 156, 158, 172, 187, 188, 192, 198, 208, 211, 214, 215, 228, 229, 231, 246; variegated, 118, 184
Syringa, see Lilac

Tamarisk, 49, 135, 172, 173
Taxation of woodlands, 271–2
Taxus, 102, 114
Tea-tree, *see Lycium*
Temperature, in Britain, 21–2, 72–3; growing season, 72–3; indoor, 39–40; in shelter, 36–7, 52, 72, 78, 143–4; leaf, 23, 50
Thinning, 164, 181, 243–6
Thuja, 110–11, 147, 150, 151, 158, 183, 188, 208, 246
Tilia, see Lime
Timber, 223, 228, 229, 255–62
Topography, 19–20, 29–30, 64, 83, 96–7, 98, 138, 199, 222
Transpiration, 49–50, 167
Transplanting, 161–3; terms used in, 236
Tree Preservation Orders, 184
Tree requirements, 231, 281
Trellis, 137–8, 145–6
Tsuga, see Hemlock
Turbulence, 19, 50, 137, 205
Turf planting, 233, 238

Ulex, see Gorse
Ulmus, see Elm
Underplanting, 246–7
Upkeep, costs of, 59, 181
Upland farm shelterbelts, 222–30

Vandalism, 181
Ventilation, in gardens, 143–4; in orchards, 188–90
Veronica, 49, 168, 174, 184, 186, 198
Viburnum, 130, 135

Walls, 45, 50, 167, 170, 184
Walnut, 121, 156
Water loss, of plants, 49–50
Wayfaring Tree, 135
Weeds, control of, 147, 160, 161, 163; shelterbelts harbouring, 53, 83; weeding plantations, 240–1
Weigela, 184
Whin, *see* Gorse
Whitebeam, 135–6, 155, 158, 172, 183, 187, 188, 198, 228; Swedish, 135–6, 153, 208
Width, of windbreaks, 157, 205
Willow, 123–4, 154, 159, 172, 183, 188, 195, 198, 206, 208, 211
Wind, cooling effect, 57, 175–6; damage, 22–3, 44, 59, 202; deformation of trees, 18, 23–4, 51, 166–7, 209; effect of topography on, 19–20, 64, 191–2, 222–3; effect of windbreaks on, 27–8, 30, 31–6, 226; erosion, 75, 81–2, 204; funnelling effect, 33, 58–9, 138–9, 176; in Britain, 17–22; in gaps, 202–3; in lee of forest, 224, 225, 227; in wooded landscape, 29–30; noises, 38–9; prevailing, 21, 139
Windbreaks, artificial, 145–6, 168; multiple-row, 156–60, 169–70, 209–22, 227–31; pleached, 148–9; productive, 190; roadside, 191–8; seaside, 166–75; shrubberies as, 148; single-row, 149–56, 173, 206–9; temporary, 167–8

Yew, 102, 114, 147, 183, 198
Yields, farm crop, 75–81, 274; horticultural crop, 51–4; milk, 87; timber, 261–2

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